Designing and testing crop rotations for organic farming

Proceedings from an International workshop

Jørgen E. Olesen, Ragnar Eltun,
Mike J. Gooding, Erik Steen
Jensen & Ulrich Köpke (Eds.)

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Danish Research Centre for Organic Farming
Foulum • P.O. Box 50 • DK-8830 Tjele
Tel. +45 89 99 16 75 • Fax +45 89 99 16 73
E-mail: foejo@agrsci.dk
Homepage: www.foejo.dk

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DARCOF Report no. 1
Printed from www.foejo.dk

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Danish Research Centre for Organic Farming 1999

DARCOF Report No. 1/1999

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Editors
Jørgen E. Olesen, Danish Institute of Agricultural Sciences
Ragnar Eltun, The Norwegian Crop Research Institute
Mike J. Gooding, The University of Reading, UK
Erik Steen Jensen, The Royal Veterinary and Agricultural University, Denmark
Ulrich Köpke, Institute of Organic Agriculture, University of Bonn, Germany

Layout
Cover: Enggaardens Tegnestue
Content: Grethe Hansen, DARCOF

Photos: E. Keller Nielsen

Print: Repro & Tryk, Skive, Denmark

Paper: 90 g. Cyklus print

Paginated pages: 350

First published: December 1999

Publisher: Danish Research Centre for Organic Agriculture, DARCOF

ISSN: 1399-915X

Price: 100 DKK incl. consignment

To be bought at
Danish Research Centre for Organic Agriculture, DARCOF
Research Centre Foulum
P.O. Box 50
DK-8830 Tjele

Tel. +45 89 99 16 75, fax +45 89 99 12 00
E-mail: foejo@agrsci.dk
Homepage: www.foejo.dk

Preface

The interest in organic farming is increasing in many industrialised countries, both as a consequence of consumer demands and because organic farming is seen as one of the ways towards sustainable agriculture.

Organic farming aims at establishing stable and harmonic farming systems, which integrate livestock and crop production. No industrial fertilisers, pesticides or growth regulators are used. The nutrient management is based on the use of animal manure, green manure, crop residues and on nitrogen fixation by legumes. Weeds, pests and diseases are controlled through the use of versatile crop rotations, mechanical weed control and a proper choice of varieties.

The multifunctional crop rotation is thus a key component in organic farming. The design of these crop rotations is a major challenge for farmers as well as for agronomic research.

The different aspects of crop rotations have been investigated by a range of methods, including long-term trials, factorial experiments and on-farm monitoring. However, there has been little effort into bringing these results and experiences together into a common understanding of the functioning of crop rotations and the methods by which they are best explored.

In this context, there is a great need for international co-operation. A workshop on crop rotations for organic farming was therefore organised in Denmark in June 1999. The workshop aimed at bringing together researchers working with different aspects of crop rotations for organic farming.

This proceeding presents the lectures given at the workshop, as well as summaries of the discussions. The desire is to contribute to the development of research in crop rotations in organic farming, and to promote the international co-operation in the area.

This would not have been possible without the efforts of the individual authors, the editorial group and the organisers of the workshop. Our sincere thanks are therefore extended to all those involved in the workshop and in the creation of this book.

Erik Steen Kristensen
Head of Danish Research Centre for Organic Farming
Foulum, December 1999

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Perspectives for research on crop rotations for organic farming

J.E. Olesen
Department of Crop Physiology and Soil Science, P.O. Box 50, 8830 Tjele, Denmark

Summary

The objective of research on crop rotations is to improve the understanding of the reasons for the benefits obtained by using crop rotations so that the design and management of rotations in practical farming can be improved. This research involves the use of a range of methods including long-term experiments, on-farm experimentation and simulation modelling. Because crop rotations serve multiple functions, there is a need to involve experts from a range of different disciplines in the design phase. Recommendation on subjects to be considered when designing crop rotation experiments are given along with suggestions for minimum datasets. There is a large need for co-ordination of on-going European long-term experiments on organic crop rotations, especially with respect to management, documentation and measurement protocols.

Introduction

Crop rotation is the practice of growing a sequence of plant species on the same land. The practice of crop rotation dates back to antiquity. Roman agronomists 2000 years ago thus recommended the practice of alternating legumes and cereals in a rotation, including the use of legumes as green manure (Karlen *et al.*, 1994). This is also a valuable practice in current organic farming systems. Some historians claim that although these rotations were recommended by Roman agronomists, they were rarely used in practice by the farmers (White, 1970). Much of this early work on crop rotations was largely forgotten with the fall of the Roman Empire, only to be rediscovered by agronomists during the 18th century. This has a parallel in current farming practice, where the use of crop rotations as such has been largely abandoned in conventional farming. Farmers who are converting to organic farming must therefore often rediscover the benefits and constraints of crop rotations.

Crop rotation is one of the very basic building blocks of organic farming systems. The crop rotation in organic farming must provide the soil fertility required for maintaining productivity and it must prevent problems with weeds, pests and diseases. This is obtained through a proper sequence of crops in time and space and through the use of N_2 fixing crops and cover crops (Lampkin, 1990). This is contrary to conventional or integrated farming systems, where lack of soil fertility can be ameliorated by use of artificial fertilisers and weeds, pests and diseases can be controlled through use of agrochemicals. Much of the research on crop rotations must therefore be designed specifically for use in organic farming systems.

This paper summarises the results of the discussions at the Workshop on Designing and Testing Crop Rotations for Organic Farming, which was held at Borris Agricultural School on 14-16 June 1999. Reference is made to some of the papers that were presented at the workshop for exemplifying some of the points made.

Objectives for crop rotations in organic farming

Crop rotations always have to serve multiple objectives, which also sometimes are conflicting giving rise to several agronomic and management dilemmas (Askegaard *et al.*, 1999b; Wijnands, 1999). When designing crop rotations and experiments involving rotations it is necessary to clearly define the goals of the crop rotation. All possible subjects related to these goals should be listed and prioritised, so that some important goals are not compromised at the expense of other major goals. Table 1 shows a list of subjects to be considered. Not all of these subjects will necessarily be important in all crop rotations, and the relevance of each subject will vary depending on many factors. In addition to these subjects focus must be on the flows and fluxes of matter and energy in the system. The flow of nutrients etc between crops in the rotation puts some of the main constraints to the rotational design (Wijnands, 1999) and so do the fluxes of nutrients in and out of the system. The rotation must also provide the conditions for optimal fluxes of nutrients into the crops.

Table 1 Subjects to be considered when designing crop rotations.

Soil quality
Soil biota (microorganisms and fauna), including mycorrhiza
Nutrient balances and nutrient availability to individual crops in the rotation
Productivity and product quality
Requirements for labour and mechanisation
Economic viability
Resource use
Weeds, pests and diseases
Allelopathy
Farming/community cycling of products and wastes
Region/community context
Sustainability
Environment effects and biodiversity
Rules and regulations
Site dependency, e.g. soil and climate

The purpose of research on crop rotations is to improve the understanding of the reasons for the benefits obtained by using crop rotations so that the design and management of rotations in practical farming can be improved. Specific objectives of crop rotation experiments also include investigating effects of current practice on the environment or comparing rotations for investigation of new possibilities for optimising cropping systems.

The rotation effect can often be attributed to increased nitrogen supply, but increased control of weeds, pests and diseases also contribute. However, these effects can not describe the entire yield increase obtained from use of fertile rotations (Bullock, 1992). The research on crop rotations involves the use of a range of methods including long-term experiments (e.g. Eltun & Nordheim, 1999; Mäder *et al.*, 1999), on-farm experimentation (Wijnands, 1999) and use of mathematical models of the system (Jensen *et al.*, 1999). Such methods are necessary because the system (soil and surrounding environment) has a memory. This memory effect depends on management, climate and soils, all of which interact over time and space.

Designing crop rotation experiments

The design of crop rotation experiments depends strongly on the specific objectives of these experiments. A number of general considerations can, however, be discerned:

- *Flexibility*. There is often a need to change management and include new aspects or investigations over the course of the experiment. Changes should be kept at an absolute minimum within a rotation course, and only introduced for each new course of the rotation.
- *Reference*. A static part (treatment) as a reference is desirable for documentation. However, even the static part should be changed/adjusted when it gets too academic.
- *Scale*. Plots/fields should be as large as possible.
- *Time*. Often long time periods from time of conversion are required for interpretation.
- *Design*. A factorial design should be used, but kept simple (from the beginning, at least). An example of the effect of such a factorial design on statistical tests is given by Olesen *et al.* (1999).
- *Management*. Detailed guidelines on the practical management of the crops and plots should be formulated in order to minimise effects of change in management over time. Management staff often a needs to learn the functions of the rotation, before proper experimentation can start.
- *Minimum dataset*. A protocol for a minimum dataset should be set up based on existing standards. This has to be absolutely minimal in order to achieve funding even in low budget years.

Because crop rotations serve multiple functions, there is a need to involve experts from a range of different disciplines in the design phase. Preferably an international group of experts should be asked when designing future experiments. As an example the needs for plot size of studies in the field of entomology are very different from those of plant nutrition.

There are also practical aspects of the experimental design. Machinery appropriate to organic farming should be used. If appropriate tools are not available, they should be designed for the crop rotation instead of the other way around.

Fulfilment of the goals of a crop rotation involves not only a sequence of crops and cover crops, but also proper use of other elements. The following list shows some of these elements, which can be used and should be developed to be able to make even more optimal crop rotations in the future:

1. Machinery with low weight
2. Machinery for soil tillage, planting and weeding
3. New species to be used as auxiliary crops (catch crops, green manures, others)
    - to be used for management of N and other nutrients
    - management of soil tilth
    - management of weeds, pests and disease
4. New main crop species (example, perennial grain species)
5. Breeding of main crops and auxiliary crops adapted to their function in organic farming
6. New green manure management tools (management in space and time)
7. Animals adapted for specific objects in organic farming
8. New methods for soil analysis

These new elements were only slightly touched upon at the workshop. The presentations in this respect mainly covered effects of legume crops on nitrogen supply of following crops (Campiglia, 1999; Larsson, 1999; Loges *et al.*, 1999), nutritional effects of organic fertilisers (Fragstein & Schmidt, 1999), effects of cover crops and sowing time in cereals on retention of nitrogen in the system (Reents & Möller, 1999), strip intercropping including sheep grazing (Jones & Harris, 1999), management of mycorrhiza (Kahiluoto & Vestberg, 1999) and use of cover crops and plant residues for weed and disease management (Brandsæter & Riley, 1999; Bødker & Thorup-Kristensen, 1999).

Testing crop rotations

Crop rotations can be tested using different experimental techniques. The most common method is the use of factorial experiments with crop rotations and related management options (Table 2) or studies with crop rotations in fields (Table 3), which allow specific factorial experiments to be carried out within the individual fields of the rotation. There are, however, also other options for studying rotation effects, including on-farm studies (Fortune *et al.*, 1999; Nauta *et al.*, 1999) or use of mathematical simulation models of the system (Høgh-Jensen, 1999; Jensen *et al.*, 1999). The lists in Tables 2 and 3 only include experiments presented at the Workshop on Designing and Testing Crop Rotations. There are several additional European long-term crop rotation experiments not represented in these lists.

Table 2 European factorial crop rotation experiments presented at the workshop.

Reference	Country	Main experimental treatments
Askegaard *et al.* (1999a)	Denmark	6-year dairy rotation; 4 different manure regimes
Eltun & Nordheim (1999)	Norway	Six cropping systems; conventional, integrated or ecological systems with 8 course rotations for either forage or arable crop production
Lacko-Bartošová *et al.* (1999)	Slovakia	Ecological/integrated 6-course rotation, +/- manure and fertiliser application, cover crops
Mäder *et al.* (1999)	Switzerland	Organic/conventional 7-course rotation, +/- fertiliser application
Olesen *et al.* (1999)	Denmark	Three sites. Four ecological 4-course rotations, +/- cover crops, +/- manure application
Paunescu & Ionescu (1999)	Romania	Four crop rotations in combination with four fertilisation regimes
Philipps *et al.* (1999)	England (UK)	Three 4-year rotations
Schmidt & Fragstein (1999)	Germany	4-year crop rotation; 4 manure regimes
Watson *et al.* (1999)	Scotland (UK)	Two sites; two ecological ley/arable rotations compared at each site; all courses of each rotation present each year
Zarina & Mikelsons (1999)	Latvia	Two factorial experiment with 5 crop rotations and 7 fertilisation treatments

Table 3 European studies involving tests of crop rotations for organic farming at field scale.

Reference	Country	Crop rotation characteristics
Asdal & Bakken (1999)	Norway	Two 6-year rotations representing an arable farm and a dairy farm
Cormack *et al.* (1999)	England (UK)	Stockless 5-year arable rotation
Mikkelsen (1999)	Denmark	6-year dairy rotation
Oudshoorn & Kristensen (1999)	Denmark	Three 5-year crop rotations representing dairy, pig and mixed production systems
Thorup-Kristensen (1999)	Denmark	6-year vegetable crop rotation

It is often problematic to compare results across different crop rotation experiments, because the measurements are not always comparable. There is therefore a need for standardised protocols for at least a minimum set of parameters. The measurements should be simple and cheap if they are to be used in all experiments, and the results should be comparable across many different soil and climate situations. Table 4 gives a suggestion for such a list of measurements, but more work and standardisation is needed if this is to be made operational.

Table 4 Basic measurements of interest for comparison of results from crop rotation experiments.

Infiltration capacity
Above ground productivity, including yield and weed biomass
Soil water holding capacity (water content at 10 kPa, and plant available water, i.e. water content between tensions of 10 and 1500 kPa)
Nutrient balances (N, P, K) at the farm-gate or field-gate
Soil analysis (total-C, total-N, Olsen-P, exchangeable K)
Use of labour, energy and irrigation water
Soil cover (%)
Carbon inputs in organic residues

Pests and diseases are not included in Table 4. Not because they are not important, but because is it difficult to suggest any simple and general methods by which to assess them. Some experiments have adopted standardised methods, although these vary between disease and pest species (Rasmussen *et al.*, 1999). Weed biomass is suggested as a measure of weed infestation, although information on single weed species would be preferable. Examples of the effects of crop rotations on several of these parameters presented at the workshop include effects on nutrient balances (Asdal & Bakken, 1999; Askegaard *et al.*, 1999a; Eriksen *et al.*, 1999), soil nutrient availability (Fortune *et al.*, 1999; Mikkelsen, 1999), weed infestation (Brandsæter & Riley, 1999; Rasmussen *et al.*, 1999) and carbon inputs (Drinkwater, 1999).

Technology transfer

Research has already produced a large amount of results on crop rotation effects, which can be better utilised by the organic farming community. This, however, involves a lot of questions and challenges, which have only marginally been addressed at the workshop, including

- effect of crop rotation design on farm profitability and farmer income
- effects on the environment
- who is actually doing the designing? The farmer, the advisor or the researcher?

Figure 1 illustrates the scales involved in transferring knowledge from research using factorial experiments to farmers and advisors. This knowledge transfer also involves the use of crop rotation experiments and pilot farms, which represent systems that are more realistic from a practical point of view but have less degrees of freedom in terms of management options that can be properly tested. This difference between research and practical oriented work is also illustrated in Table 5. Both the factorial crop rotation experiments and the whole rotation studies are very well suited for holding field demonstration days. The farm manager at the research station has a very important role to play in this respect.

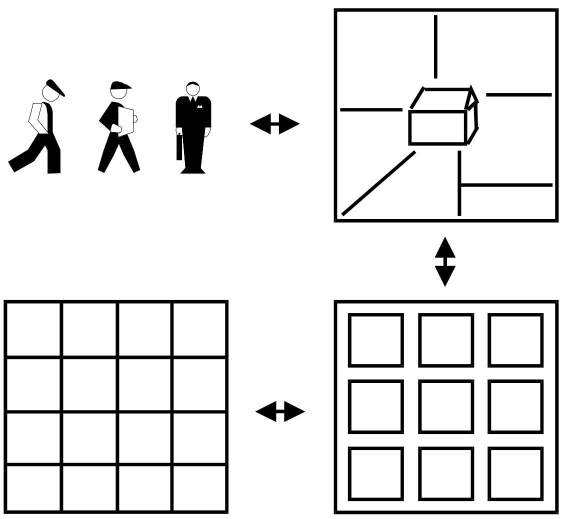

Figure 1 Interaction between farmers/advisors, on-farm research, crop rotation experiments and factorial plot experiments.

Table 5 Characteristics of research on crop rotations and work on practical farms.

Research	Practice
Specific objectives	Multiple objectives
Small scales	Large scales
Many replicates	No replicates

Recommendations for research

The term "long-term" needs to be better defined with respect to crop rotations experiments. There may be different time scales involved when considering impacts of the crop rotation on different indicators of sustainability. Use of long-term experiments in combination with on-farm studies and simulation modelling may be a way to explore and solve some of these problems. The aims of such research should, however, be clearly stated prior to initiation.

It is important that long-term experiments retain their basic design characteristics over the time-frame required to determine whether the rotations are sustainable with the respect to the characteristics specified in the objectives of the study. Any changes in the design should be made as a reaction to an analysis of the performance of the systems resulting from measurements carried out within the experiments. This, however, makes it very difficult to be proactive or innovative in the management of such experiments.

There is a need for more studies on the below-ground parts of the crops in the rotation. Net below ground productivity may thus play an important role for carbon and nitrogen turnover in the system (Drinkwater, 1999), and so may the carbon and nitrogen cycling processes at the root surface (Høgh-Jensen, 1999).

The current and on-going European experiments on crop rotations in organic farming are not co-ordinated. There is a great need to standardise experiments with respect to management, documentation and measurements protocols. There is also a need for providing comparable minimum datasets, which can give the basis for comparison of results from the different sites. This should be extended with the provision of well-defined datasets, which are freely available for the modelling community for model calibration and validation.

Collaboration and exchange of knowledge between researchers from different disciplines is important and required for improving crop rotations. Examples could be leaching and crop protection. There must also be collaboration with economists. Collaboration could be organised as EU-projects, concerted actions, workshops or networks, but it is important to have clear goals as crop rotation research spans a very wide range of traditional research disciplines.

Acknowledgement

This paper is the result of discussions at the Workshop on Designing and Testing Crop Rotations for Organic Farming. The contributions of all participants and in particular of the chairmen and rapporteurs of the discussion groups are gratefully acknowledged.

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Crop rotation in organic farming: theory and practice

F.G. Wijnands
Applied Research for Arable Farming and Field production of Vegetables,
P.O.Box 430, NL 8200 AK, Lelystad, The Netherlands

Summary

In this paper the central role of crop rotation in organic farming is highlighted. Theory and practice are confronted and recommendations for research and practice formulated. The major functions of crop rotation are the prevention and control of pests, diseases and weeds and the maintenance and improvement of soil fertility. These functions are elaborated in detail. There appears to be a strong interaction between crop rotation and nutrient management. This interaction forms the basis for quality production. This means that both crop rotation and nutrient management should be carefully designed in their mutual dependency as basic strategic elements of viable and productive organic farming systems. The design procedure is demonstrated in detail in the paper. The practical difficulties are discussed and illustrated by the experiences from a national pilot farm network of organic farms in the Netherlands.

Prototyping more sustainable farming systems in the Netherlands

European agriculture is currently entwined in a complex of problems, mainly caused by the one sided development of farming with the emphasis on intensification. The first step towards more sustainable farming is to establish new integral concepts of farming. Such integral approaches are at present mainly represented in two major visions: integrated and organic farming systems. To develop and implement these more sustainable farming systems, new concepts in research, technological development and knowledge transfer are needed.

The methodological way to design, test, improve and implement/disseminate such systems is called prototyping and was elaborated in an EU concerted action (Vereijken, 1994, 1995, 1996, 1998). Over the last 20 years integrated and organic systems have been developed all over western Europe either on experimental farms (Vereijken & Royle, 1989; Vereijken, 1994) or in co-operation with commercial farms as innovative pilot farms (Vereijken, 1997; Wijnands 1992; Wijnands *et al.*, 1998; El Titi, 1998).

Prototyping can be characterised as a synthetic research/development effort starting off with a profile of demands (objectives) in agronomic, environmental and economic terms for a more sustainable farming and ending with tested, ready for use prototypes to be disseminated on a large scale (Wijnands, in press). In the Netherlands extensive experience has been built up with this methodology (Table 1).

Based on the analysis of the shortcomings of current farming and the perspectives in the future a hierarchy of objectives for either an integrated (short-term alternative) or ecological (long-term alternative) farming systems has to be established. In the prototyping methodology the hierarchy of objectives is based on a standardised well-defined set of objectives and a standardised procedure to elaborate this hierarchy (Vereijken, 1992). Each general value can be specified in specific objectives (between brackets); food supply (sustainability, stability, accessibility, quality and quantity), employment (farm, region, national), basic income/profit (farm, region, national), abiotic environment (water, soil, air), nature/landscape (flora, fauna and landscape), health/well-being (farm animals, rural or urban population).

Table 1 Overview of farming systems research for arable and vegetable farming systems in The Netherlands.

	Location	Soil	Period 1	Period 2	IFS	OFS	CFS	Ref.
1. Prototype development on experimental farms								
Arable farming systems	Nagele	clay	1979-1990		•	•	•	1
				1991-	•	•	-	1
	Borgerswold	sand/peat	1986-1995		•	-	•	1
	Vredepeel	sand	1989-1992		•	•	-	1
				1993-	•	•	•	-
	Kompas	sand/peat		1997-	•	-	-	-
	Kooijenburg	sand		1997-	-	•	-	-
Vegetable farming systems	Zwaagdijk	clay	1990-1996		•		•	2
	Breda	sand	1990-1996		•		•	2
	Meterik	sand	1990-1996		•		•	2
				1997-	•	•		
	Westmaas	clay	1990-1996		•		•	2
				1997-	•	•		
2. Pilot farms small scale								
Integrated arable farming	38 farms	all	1990-1993		•			3,4
Integrated vegetable farming	18 farms	all	1996-1998		•			-
Integrated arable/vegetable farming	30 farms	in prep.	2000-2005		•			-
Ecological farming (BIOM)	25 farms	all	1998-2001			•		-
3. Pilot farms large scale								
Integrated arable farming	500 farms	all	1993-1995		•			-
Ecological farming (BIOM)	40 farms	all	1998-2001			•		-

Ref. 1: Wijnands and Vereijken (1992), Ref. 2: Sukkel *et al.* (in press), Ref. 3: Wijnands (1992), Ref. 4:Wijnands *et al.* (1998). IFS = Integrated Farming Systems, CFS = Conventional Farming Systems, OFS = Organic Farming Systems.

These rather abstract objectives are in the NL prototyping practice translated in 5 directional themes: quality production, clean environment, attractive landscape and diversified nature, sustainable management of resources and farm continuity (Table 2 for NL). Table 2 also shows the main points of interest within each theme. The themes cover the full width of a farming system and are of equal importance. Each theme is concretised in a number of multi-objective (farm level) parameters to be able to quantify the objectives of the theme. Each parameter is given a target value so that a well defined, documented and clear framework is elaborated to design test and improve farming systems (Wijnands, in press).

Table 2 Directional themes of research and relevant topics (potential parameters).

Themes	Relevant topics, parameters
Quality production	Quantity and quality of production
Clean environment	Pesticide and nutrient use, emission and potential damage, nutrient accumulation
	Fossil energy use
Attractive landscape and diversified nature	Quantity and quality of ecological infrastructure on farm
Sustainable management of resources	Soil fertility, soil erosion, water- and energy use,
	use of non-renewable resources
Farm continuity	Net farm profit, savings

In Figure 1 the relation between the themes and the (traditional) farming methods is given. The farming methods have to be redesigned in order to realise the related objectives. Therefore not only a general strategy is needed for each method but also the concretisation in a mixture of methods and techniques. This often requires a critical synthesis of existing knowledge and/or the development of new technology. The challenge in this process is to overcome apparently conflicting objectives. Finally a new style method is developed as a coherent *multi-objective strategy* that is safe and flexible and utilises a diversified set of techniques (*toolbox*), dependent on the specific conditions on the farm and the growing season. It is essential that problems are analysed and solved in the full farm context.

Crop rotation is such a redesigned new style method is of unequalled importance in organic farming. In this paper the central role of crop rotation in organic farming is highlighted. Theory and practice are confronted and recommendations for research and practice formulated

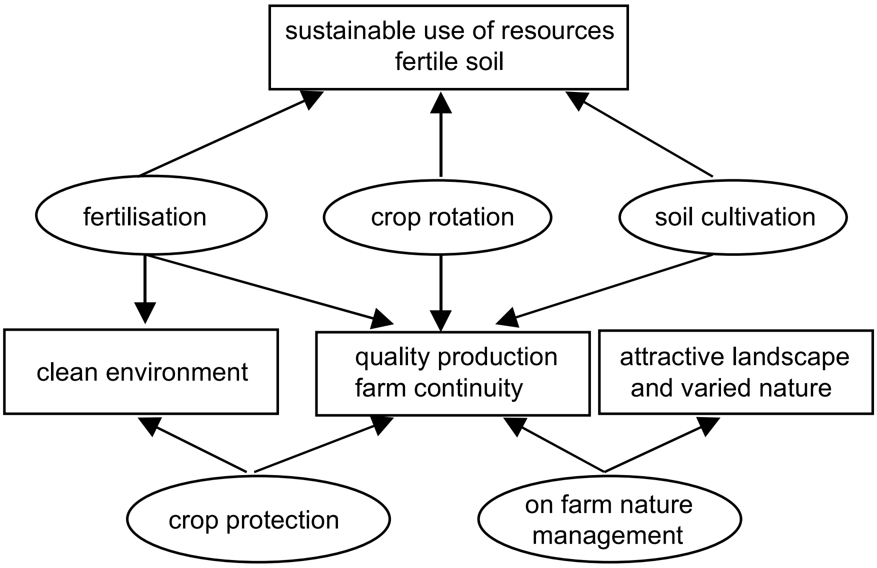

Figure 1 Methods and themes in more sustainable farming systems.

Organic farming, themes and priorities in the Netherlands

Organic farming has become increasingly part of the prototyping work in the Netherlands (Table 1). Recently the work on experimental farms found it's logical progression in a national pilot farm network directed on Innovation of and Conversion to Organic Farming. Objective of this project called BIOM (1998-2002) is to strengthen organic farming in practice. BIOM works on different levels: firstly some 25 existing organic farms are participating as innovative pilot farms in close co-operation of farmers, extension and research. Secondly 45 farms are guided in optimisation groups. Thirdly, conventional farmers that are interested in conversion are technically prepared in 5 day courses. Finally market- and farm economic perspective studies will contribute to overcome the existing lack of reliable economic information. Organic farms in the Netherlands grow arable crops in combination with vegetables. The participating farms in BIOM grow over 80 different crops.

By the close co-operation of research, extension and practice knowledge, expertise and innovations will flow more easily between the groups. Moreover a sharp and clear picture will emerge of the threats and opportunities for organic farming Opportunities will be used and threats counteracted and solved. Based on an analysis of the current shortcomings in the practice of organic farming (BIOM farms) the required innovations in organic farming are described per theme (Table 3).

Table 3 Innovation objectives for Organic Farming in practice, described per theme.

Quality production
Improve and stabilise production quantity and quality, minimise losses between harvest and trade, Improve control of pest and diseases and optimise tuning of N supply to N demand.
Clean environment
Limit N leaching, prevent accumulation of P and heavy metals, abandon use of ecosystem endangering so called "biological pesticides".
Attractive landscape and diversified nature
Strengthen and protect the current ecological values on the farm, integrate it in an ecological infrastructure, enhance a liveable landscape for man, flora and fauna.
Sustainable management of resources
Maintain and/or improve biological, physical and chemical soil fertility by a wider and more diversified crop rotation, well-focused use of organic manure and (leguminous) green manure. Improve organic matter management and control soil health.
Farm continuity
Safeguard income and farm continuity by strengthening the quality production. Develop strategic farm management that includes a careful planning of farm activities based on a coherent vision on the desired farm development. Important points are planning of crop rotation and fertilisation, labour organisation and integral quality chain care.

Crop rotation in theory

Crop rotation is the term used to express that crops are grown over time in a very specific order (crop sequence, for definitions of terminology, see Table 4). After a number of years (length of the crop rotation) the cycle will be repeated. The crops grown in one year on the available area of a farm constitute together the cropping plan. If the crop rotation is consistent and unchanged the cropping plan is the same every year. So crop rotation has a temporal aspect: crops are grown over time in a specific order (succession of crops in time) and a spatial aspect: the crops grown this year and their division over the available space. The interaction between spatial and temporal aspects can be used to strengthen the crop rotation concept. Rotating the crops over the available space in such a way that a given crop is never grown adjacent to a field where the preceding crop was the same (spatial crop rotation), contributes to the prevention of transfer of semi-mobile pests and diseases from one year to the other.

Moreover an optimal agro-ecological lay-out over all the farm will contribute strongly to the stability of the ecosystem and support the functions of the crop rotation. Additional criteria can be formulated with regard to the lay-out like: field adjacency, field size, field length and width, adjacency of subsequent crop rotation blocks (spatial crop rotation) and the ecological infrastructure (Vereijken, 1994).

The crop rotation consists out of a number of crops grown in a specific order. The added value of this team of players (crops) increases the more attention is given to a careful design of the rotation: finding an optimum team and line-up. The team (crop rotation) is more then the sum of the players (crops). Some of the players can only score well if their performance is carefully prepared by others (preceding crop). Target of the crop rotation is offering appropriate, optimal and homogenous conditions to all the players in the team. This is the basis for sustainability quality production.

Table 4 Definitions in crop rotation terminology.

Crop rotation	Carefully designed sequence of crops in which the succession is highly beneficial
Cropping plan	The partitioning of crops over the available area in a given year, often represented as % of the area for each crop (space)
Crop sequence	The succession of crops in time on one field in particular (time)
Crop frequency	The frequency of cropping the same crop on the same field, usually expressed as once in a number of years, for instance 1 out of 3, 1:3, meaning once every three years
Crop rotation block (course)	One year of the crop rotation succession and the crop(s) in that specific crop rotation year
Agro-ecological layout of the farm	The layout of the farm over the available space, the partitioning of the area over fields, their shape and size, the spatial crop rotation and the ecological infrastructure of the farm
Ecological infrastructure	The network of natural and specifically managed areas on the farm to provide habitats and (transport) corridors for flora and fauna

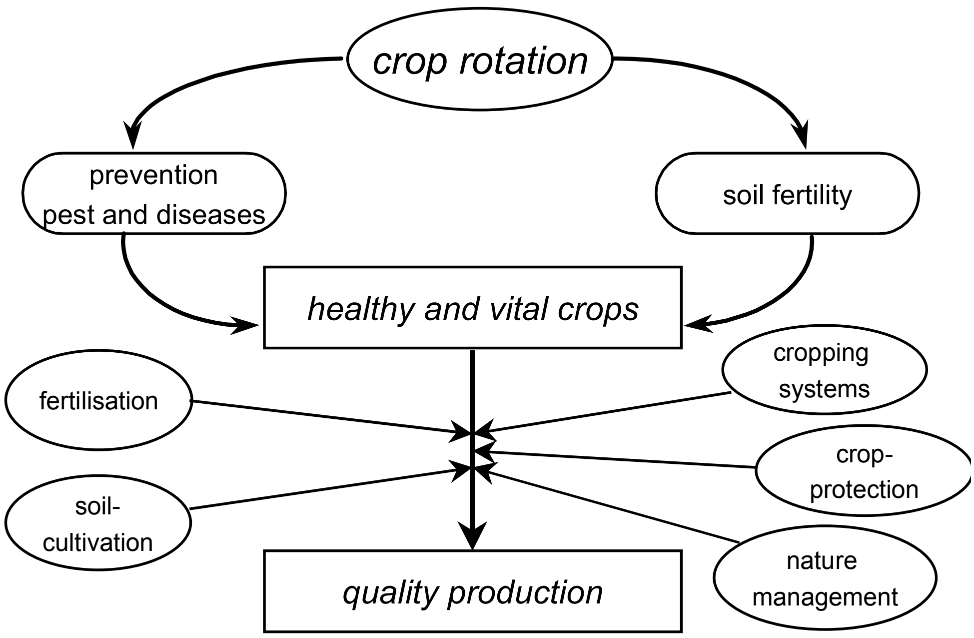

Figure 2 Quality production as a function of crop rotation

The first step in the design of a farming system is the design of the crop rotation. The prerequisite is an understanding of the role and potential of crop rotation in general and in organic farming in particular. The major functions of crop rotation are the prevention and control of pests, diseases and weeds and the maintenance and improvement of the soil fertility as shown in the diagram in Figure 2. This can ensure an optimal quality production with minimal external input like pesticides, fossil energy, machinery and fertilisers. Quality production is based on healthy and vital crops as determined by the crop rotation. This potential has to be transformed in quality production by the support of the cropping systems and the other farming methods shown in Figure 3.

Prevention/control of pests, diseases and weeds
Figure 3 depicts the role of crop rotation for the prevention and control of pests, diseases and weeds (after Vereijken, 1994). Pests and diseases can be distinguished along two axes. On the x-axis the organisms change from non-mobile, mostly soil borne to very mobile, mostly airborne. On the y-axis the organisms change from very specific (mostly monofageous) to non-specific (mostly polyfageous). Crop rotation is of increasing importance moving from the right-hand lower corner to the left-hand upper corner. Every quadrant of Figure 4 will be discussed below.

Specific and non-mobile (upper, left-hand corner): It mostly concerns soil born pests and diseases, like the cyst nematodes and *Rhizoctonia spp*. Classical crop rotation, which means sufficient low crop frequency of the organisms favourite crop, is usually sufficient. Resistant and tolerant cultivars support this approach.

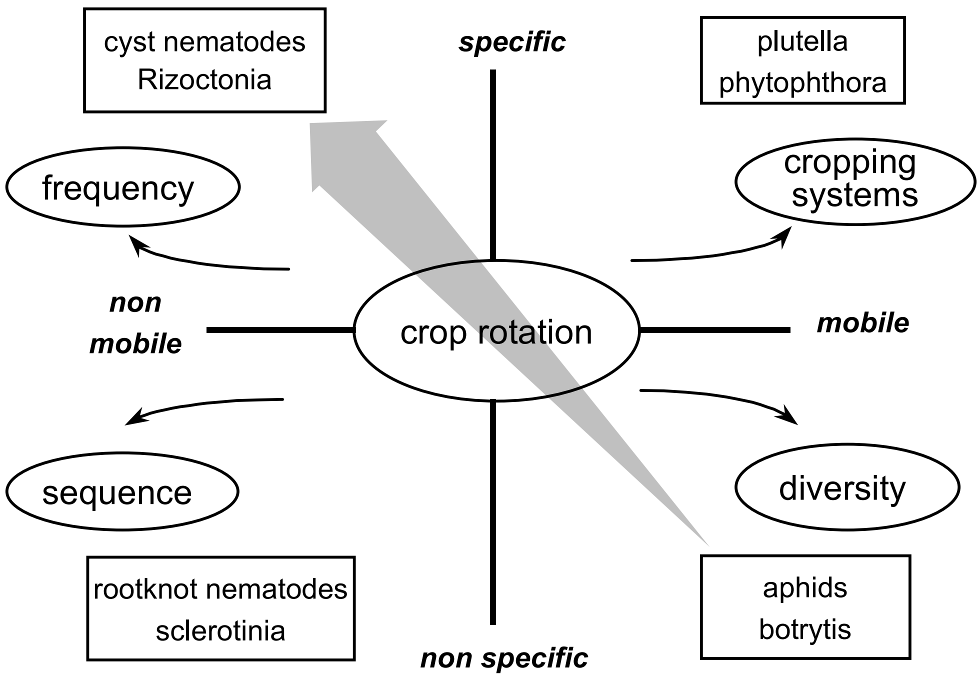

Figure 3 Crop rotation in relation to mobility and specificity of pests and diseases.

Non-specific and non-mobile (lower left-hand corner): this concerns also mostly soil born pests and diseases like *Sclerotinia* and root knot nematodes. Then the composition of the crop rotation becomes important; which crops are grown and in which sequence. Support for this approach can be found in the cropping system (sowing date, cultivar choice etc) depending on the organism involved.

Specific and mobile (upper left-hand corner): concerns organisms like *Plutella* and *Phytophthora*: classical crop rotation is not helpful here, although spatial crop rotation (see crop rotation in theory) can contribute to the control of semi-mobile, specific pests and diseases. Other solutions might be found in the cropping systems (cultivar choice, sowing date, crop structure etc.). Control measures in the crop might be necessary, like physical cover or the use of "biological pesticides".

Non-specific and mobile (lower right-hand corner): many pests and diseases. Crop rotation is of no use, although crop diversification might be helpful, especially when applied on a regional scale (diversification in space). Again the design of cropping systems can contribute to prevention.

In the latter two categories direct control in crops becomes increasingly important. This function might be fulfilled by natural enemies. Hence they have to be stimulated by a carefully designed and managed ecological infrastructure on the farm that offers year round shelter and food (functional biodiversity). Then also aspects like shape and size of fields and the total farm (parcel) layout become increasingly important, i.e. the agro-ecological layout of the farm.

The crop rotation is also very supportive for the control of weeds by creating a diversified set of growing conditions (not selecting specific species) and control options.

Maintenance and improvement of soil fertility

The crop rotation plays a central role in maintenance and improvement of soil fertility in the broadest sense, including soil physical (structure), soil biological (soil biota, positive and negative) and soil chemical aspects (nutrient reserves and organic matter composition). The interaction between crops, soil, cultivation, fertilisation and weather determines the soil fertility, which is dynamic in time and space (Figure 4).

Fertilisation here is defined as the targeted supply of nutrients to the soil. Organic matter supply concerns the maintenance or improvement of organic matter reserves in the soil. Nutrient management is the term used to express the management of organic matter and nutrient dynamics in time and space. Since organic manure is the most common source of nutrients in organic farming, organic matter supply and fertilisation is strongly intertwined. Moreover the release of nutrients from the complex organic manure and the soil reserves is a process that is embedded in the dynamics of the soil fertility. Therefore nutrient management in the broadest sense is of more importance in organic farming than in other farming systems.

Nutrient management in organic farming should aim to: maintain chemical soil fertility in an agronomic desired and ecologically acceptable range (no accumulation), maintain or improve organic matter supply, supply the crops at the right time with the needed nutrients and minimise the losses of nutrients, in particular nitrogen.

Crop rotation on an organic farm strongly interacts with nutrient management by the characteristic and specific role of crops and crop sequences in this process: nutrient demand, efficiency of use in time and space, N-fixation, amount and composition of organic residues and nutrient transfer to the next crops.

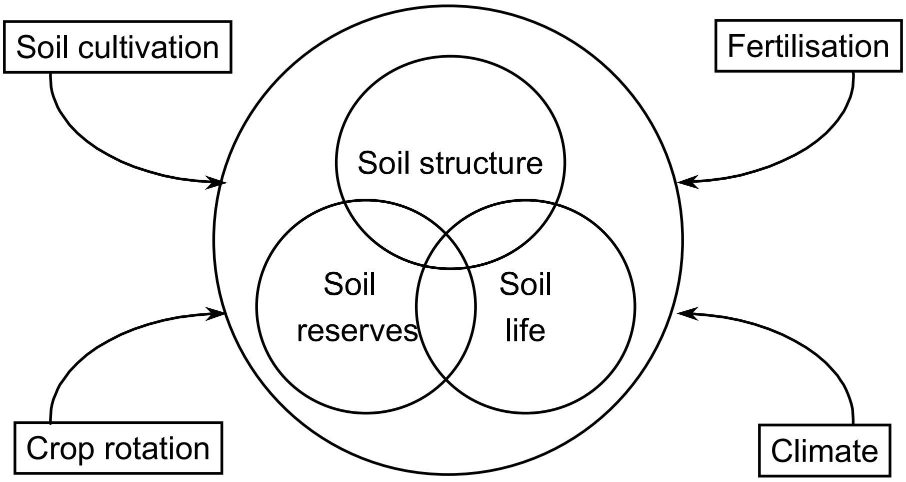

Figure 4 Soil fertility complex in relation to external factors.

As a consequence of the aim to maintain chemical soil fertility within an agronomic desired and ecologically acceptable range, the input of nutrients, especially P and K has to be limited to the level of the output of P and K plus the unavoidable losses. In the Netherlands the unavoidable losses are considered to be some 20 kg P_2O_5 and 20-50 kg K_2O per ha (unavoidable means necessary to maintain the same level of plant available nutrient reserves). Since the usual source of P_2O_5 and K_2O is organic manure (a composite fertiliser), it also means that the total N-input is limited. The availability and release pattern (mineralisation over time) of N moreover is determined by the type of manure and the time and technique of application. In many crop rotations additional N then is needed from N fixation by leguminous crops to cover the demand of the crops.

The limited availability of N from organic manure and the need for additional N from leguminous crops has large consequences for the crop rotation:

- The total N demand of the crops in the rotation should be lower or equal to the cumulative amount of N that is available from organic sources (manure, green manure, crop residues and soil mineralisation dependent) and from "mineral" fertilisers and N-fixation.
- The sequence of crops in the rotation, the use of green manures and the organic manure applications have to be carefully planned in relation to each other in order to synchronise demand and availability of nutrients and to minimise the losses.

When the crop rotation is carefully planned in the way described above, a specific rotation and nutrient management pattern of soil fertility dynamics will develop. Appropriate and homogeneous conditions for each crop will then not only guarantee optimal quality production but will also help to safeguard the environmental quality by limiting the N losses.

Design of a conceptual model of Multifunctional Crop Rotation (MCR)
Before elaborating a specific and concrete crop rotation for a specific situation a *conceptual model* of a Multifunctional Crop Rotation has to be formulated. This conceptual model is built upon the insight and understanding of the two major functions of crop rotation (as explained above) and the strong interaction of crop rotation and nutrient management. In a conceptual model of the crop rotation every course of the rotation has a specific function.

The elaboration of the model starts with a set of simple rules derived from these insights. For the Netherlands the first determining rules are:

- Limit the frequency of specific crops to 1:6 and the frequency of phytopathologically related groups of crops to 1:3 (pests and diseases).
- Alternate root crops and combinable crops. By doing so, the financially high yielding root crops are given the best position (soil fertility, especially soil structure).

The crop grown in a specific year of the rotation (course) will grow under the conditions created by the preceding crop and will in its turn contribute to the heritage of the next crop, as illustrated in Figure 5. In this way every course has it's own identity, it's own function (for instance soil fertility restoring, utilising the high N delivery from a preceding grass/clover year, offering excellent opportunities to control weeds before a crop with more difficulties etc.). Lining up a model facilitates the choices of crops when changes have to be made in the crop rotation.

An example of a conceptual model used for organic arable farming in the central clay area of the Netherlands is given in Table 5. From this conceptual model it is also clear which type of crops can be grown in a specific year. In this sense crops can be substituted as long as their characteristics fit into the position in the crop rotation.

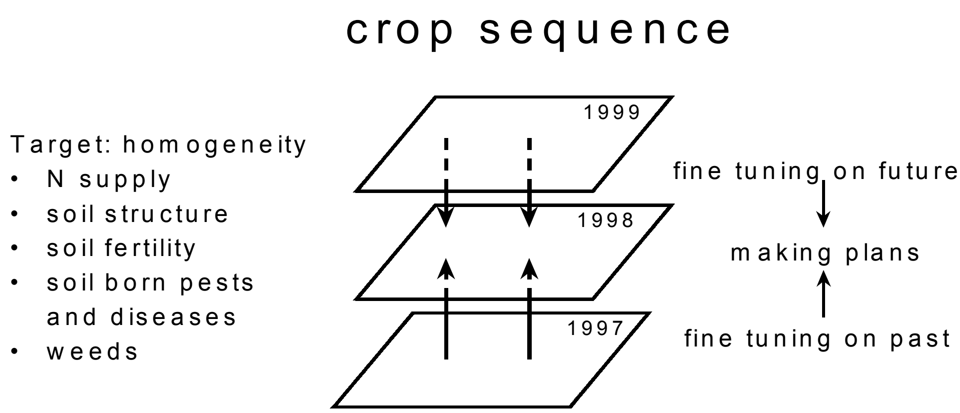

Figure 5 Planning of the crop rotation includes looking backwards and forwards in time.

Not following the functionality of a course in the rotation will always lead to problems. For instance when more than one crop is cropped in a specific crop rotation block, the demands that these crops have for their starting position and their impact on the crops of the next course should be comparable. Otherwise the uniformity of quality production is endangered. Moreover when the fertilisation is adapted to the specific needs of each crop in a course of the rotation, the parcel becomes fragmented in terms of soil fertility. In this sense the ideal could be one crop per course.

The functionality of the crop rotation should always be checked carefully in practice, since one of the potential dangers is that the designed rotation is out of balance with respect to one of the factors earlier mentioned as prevention of pests, diseases and weeds or maintenance of soil fertility. The imbalance might originate from short-term economical interest that overshadows long-term sustainability.

Table 5 Conceptual Multifunctional Crop Rotation model for arable organic farming in the central clay area in the Netherlands (Courses (crop rotation blocks) in time sequence).

Course	Function	Crops examples	Green manure	Organic manure
1	Root crop Moderate N demanding crop	Seed potato	Grass clover (see year 2)	
2	Mowable crop Soil fertility restoring year No additional N needed	Grass/clover, Cereal	None Undersown white clover/grass	Solid straw-rich manure in stubble
3	Root crop High N demanding, late crop	Cabbage, seleriac	none	
4	Mowable crop Soil fertility restoring year Moderate N demanding crop	Cereals	Undersown white clover/grass	
5	Root crop Low N demanding crop	Carrot, chicory	None	
6	Mowable crop Soil fertility restoring year No external N needed	Canned peas	Ryegrass	Solid straw-rich manure in stubble

Practical design of a Multifunctional Crop Rotation

The designed conceptual Crop Rotation Model (type of crops, frequency and sequence) has to be translated into a concrete specified rotation for the specific target situation. Therefore two steps have to be taken:

1. Select and characterise *potential crops* with respect to;
   a) Production-ecological characteristics, marketability and profitability (soil, climate, infrastructure, market, auctions, industry, labour-, capital- and machinery demand etc.),
   b) Which genetically and phytopathologically related group they belong (legumes, crucifers etc.),
   c) Their potential role concerning;
   a) Prevention and control of pests, diseases, weeds (resistance, tolerance and required or possible control measures),
   b) Physical soil fertility (especially effect on soil structure on compaction-susceptible soils),
   c) Chemical soil fertility (N need, -offtake, -transfer, organic matter supply),
   d) Cropping period and soil cover (soil protection for erosion-susceptible soils).
2. Design of the *rotation* with a maximum of positive and a minimum of negative interactions between the crops. Take into account:
   a) Prevention and control of pests and diseases by the crop rotation composition: crops, frequencies and sequence,

b) Soil fertility in the broadest sense and in particular organic matter- and N dynamics,
c) Diversification impulses / options (pest, disease and weed control),
d) Feasibility crop sequence in terms of harvest time, crop residues and volunteers from preceding crops,
e) Agronomic optimal use land, labour and equipment.

In the practice of designing crop rotations there is a strong feedback between the elaboration of the model and the design of a concrete, specific crop rotation.

Crop rotation in practice

Making a good plan is already difficult, however implementing it in a correct way in space and time in the very diversified reality of farming practice is even harder. The practical difficulties will be discussed and illustrated by organic farms in the Netherlands

Layout in practice, crop rotation over the years
Fitting the crop rotation in the given specific physical conditions of the farm is often a puzzle in itself. The difficulties are constituted by the number and size of the available fields and the limitations of use. Often several crop rotations are needed when the farm consists out of quite different soil conditions. Apart from this, finally each block of the crop rotation is placed on one or more fields. This gives planning problems when a course in the rotation consists of more than one crop.

The temporal aspects make it even more complicated. The crop rotation sequence should be followed on each of the fields over the years. Commonly experienced difficulties are changes in crops or area per crop. This might be appropriate given the market conditions and possibilities. However, changes in crops should be done according to the conceptual MCR model. Shifts in area per crop from year to year are threatening the homogeneity, even more if the crops within one course of the rotation differ in role and characteristics.

The "hard" reality
From the inventories (1998) done on the 65 existing organic farms that participate in the earlier mentioned BIOM project, a sharp picture can be deduced of crop rotation in practice.

Only a limited number of the farmers have a clear view on their crop rotation plan when asked to present it. When confronted with their cropping plans of the past years, large discrepancies appears between the plan and the reality. So when a crop rotation plan is defined as something that is followed quite carefully in practice then about 60% of the farmers have no crop rotation plan. The reasons will be discussed later, first more details will be given:

- Crop rotation plan, composition of the cropping plans;
  - On average each crop rotation block has 1.7 crops, which means that the participating farms grow on average more than 10 crops when it is assumed that most farmers use a 6 year crop rotation model,
  - The share of leguminous crops (excluding green manure catch crops) in the cropping plans varies per region from 12 to 25% with an national average of 20%,
  - On average some 50% of the area per farm consists of combinable crops, the rest is filled up with root crops and leaf crops (vegetables),
  - Green manure crops are rarely used, especially the use of leguminous green manure is on average limited to only 4% of the total farm area,

- On average on some 8% of the area the guideline of maximum 1:3 crops of the same group is exceeded,
- From the 20 most important crops (in terms of total area) in the project, 7 clearly exceed in many cases the 1:6 rule, this includes crops such as potato, cabbage, wheat, pumpkin, pea/bean, lettuce, maize etc.
- On average on some 18% of the area the guideline of maximum 1:6 of the same crops is exceeded.

➢ Crop rotation, spatial aspects;
  - The average number of parcels per crop rotation block is on average 1.5 when it is assumed that most farmers use a 6-year crop rotation model.

➢ Crop rotation, temporal aspects;
  - From an analysis of the temporal aspects of the crop rotation on those participating farms that have an organic history longer than 3 years it appears that the sequence of crops is often altered. The same crop thus has over the years different preceding crops and even different compositions of preceding crops,
  - Moreover the homogeneity of crops grown together in one course of the rotation is often insufficient, thus leading to inappropriate starting positions for those crops and often also for the succeeding crops.

Most of the farmer's use in principle a six-year crop rotation. It consists of some 50% combinable crops. The rest are root and leaf crops. So in principle the ingredients are there for a proper crop rotation. However specific, apparently important crops for farmers, are over-represented and thus grown too intensively. Also the diversification over different crop groups receives too little attention, leading again to too intensive crop rotations. The large number of crops that are grown together in one crop rotation block with the average 1.5 parcel per course in the rotation makes planning very complicated.

For most farmers crop rotation only seems to be a vague outline and notion and not a concrete and carefully planned and implemented reality. In their practice crops in general are changed a lot, too often crops change from preceding crop and the crops grown together in one course in the rotation are not only often not of comparable demands and characteristics but they also keep on changing, also in relative area. This leads to fragmented parcels in terms of soil fertility and passing information to the next year. Also it leads to heterogeneity and thus endangers the sustainability of quality production.

Confrontation theory and practice, lessons to be learnt

Crop rotation plays a central and crucial role in the basic design of an organic farm. It is not only the major weapon to prevent and control pests, diseases and weeds but it is also the basis for maintenance and improvement of soil fertility. Crop rotation cannot be separately planned from nutrient management. These two themes strongly interact on an organic farm. When properly designed the crop rotation and nutrient management creates a rhythm of soil fertility dynamics, that is the basis for quality production. Homogeneity and the right rhythm are the key factors for success.

The two factors that are threatening this approach are the farmer and the external conditions. Farmers are insufficiently aware of the concept of crop rotation and have too little experience of its benefits. Crop rotation as a central part of agronomy has lost significance in the technology (machines, pesticides and mineral fertilisers) driven rationalisation and intensification race over the past five decades. Research and extension should reappraise the value of crop rotation. However this seems to be rather difficult since it also requires more generalist and architectural skills, another virtue that has been lost in the intensification race. Therefore many modern crop rotation experiments suffer from insufficient scope and overview.

Nutrient management in organic farming is not yet adapted to the specific boundary conditions and targets of sustainability: maintaining an appropriate soil fertility level does not mean increasing it to a level that is ecologically endangering, using organic manure does not mean that N losses are limited. When the nutrient management will have to be adapted to these demands, the need for a proper planning of crop rotation in accordance with nutrient management will strongly grow. Farmers in organic farming will have to be supported by skilled and experienced generalists.

The most important external disturbing factor is the market. Organic farming is growing very fast, markets are expanding and many new players are on the field. It means that opportunities and perspectives of crops can change rapidly. Farmers tend to follow these market dynamics. However when not properly and carefully fitted into the crop rotation the dynamics of the market can turn the farm into a chaos and destabilise the sustainability of quality production.

"Ecologising" agriculture requires a profound knowledge of agronomy and ecology and the ability to envisage the coherency of processes. When these skills are developed and used to develop the concepts of organic agriculture, substantial progress can be made towards a more sustainable agriculture that meets the demands of the society in the 21 century.

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Using plant species composition to restore soil quality and ecosystem function

L.E. Drinkwater
Rodale Institute, 611 Siegfriedale Rd., Kutztown, Pennsylvania, USA

Summary

Crop rotation can have a major impact on soil quality and function through a number of mechanisms, including differences in belowground net primary productivity, timing and composition of root turnover and root exudates, litter quality, tendency to foster the formation of soil aggregates, and changes in microbial community structure and function. For instance, plant species commonly used as cover crops and green manures tend to promote stable aggregate formation more effectively than do many cash crops. Likewise, tillage should be minimised as much as possible and should reflect the conditions at the time of planting. Strategic use of tillage can improve nutrient management, reduce soil degradation and still provided adequate weed suppression. The increased understanding of plant species effects on below-ground processes presents the opportunity to manage species composition of plants to favor C and N retention which will have significant benefits in terms of soil quality and restoration of ecosystem function.

Introduction

Soil degradation is a widespread problem having negative consequences for both agricultural productivity and natural ecosystems. The vast majority of agricultural lands under annual crop production already have depleted levels of soil organic matter (hereafter, SOM; Campbell & Zentner, 1993; Lee & Phillips, 1993). Nutrient losses through leaching and soil erosion are significant and in many cases soil erosion exceeds sustainable rates (Pimentel *et al.*, 1995; Carpenter *et al.*, 1998). Common short-comings of intensive cropping systems include: insufficient carbon (C) additions to maintain SOM, the return of only low quality, high C, senescent organic residues to the soil, nutrient inputs that exceed harvested exports (Carpenter *et al.*, 1998), excessive tillage or tillage at a time that exposes soil to wind and water erosion, rotations that include long fallow periods and use of temporal monocultures.

The combined effects of tillage, crop rotation, inputs of organic residues and mineral fertiliser and irrigation, which accelerate or restrict mineralisation and also affect primary productivity, influence equilibrium levels of soil C and N and hence are major factors in determining whether agroecosystem function is maintained or degraded. Soil quality is one major component of ecosystem function however, the ecosystem processes impacted by soil management decisions are much broader in scope. Optimisation of SOM cycling is essential if crop yields and ecosystem function are to be maintained (Figure1). In order to restore and preserve ecosystem function, soil management practices should maximise the capacity for sustained primary production, nutrient retention and water infiltration while maintaining the integrity of the soil community.

Recognition of the central role of SOM in maintaining soil quality and plant productivity is the central principle guiding soil management strategies in organic agriculture. Many common soil management practices used by organic farmers are known to promote biological nutrient cycling and conservation of soil organic matter. The potential for designing rotations that optimise biological nutrient cycling while building SOM levels and enhancing soil health has not been fully explored. Although organically-managed systems routinely use many practices that are known to build soil fertility while reducing negative environmental impacts, tillage regimes in annual production systems remain intensive. This paper will examine the potential for integrated design of crop rotations with suitable tillage strategies to enhance soil processes. Mechanisms leading to increased levels of SOM, improved nutrient use efficiency and restored ecosystem function will be discussed.

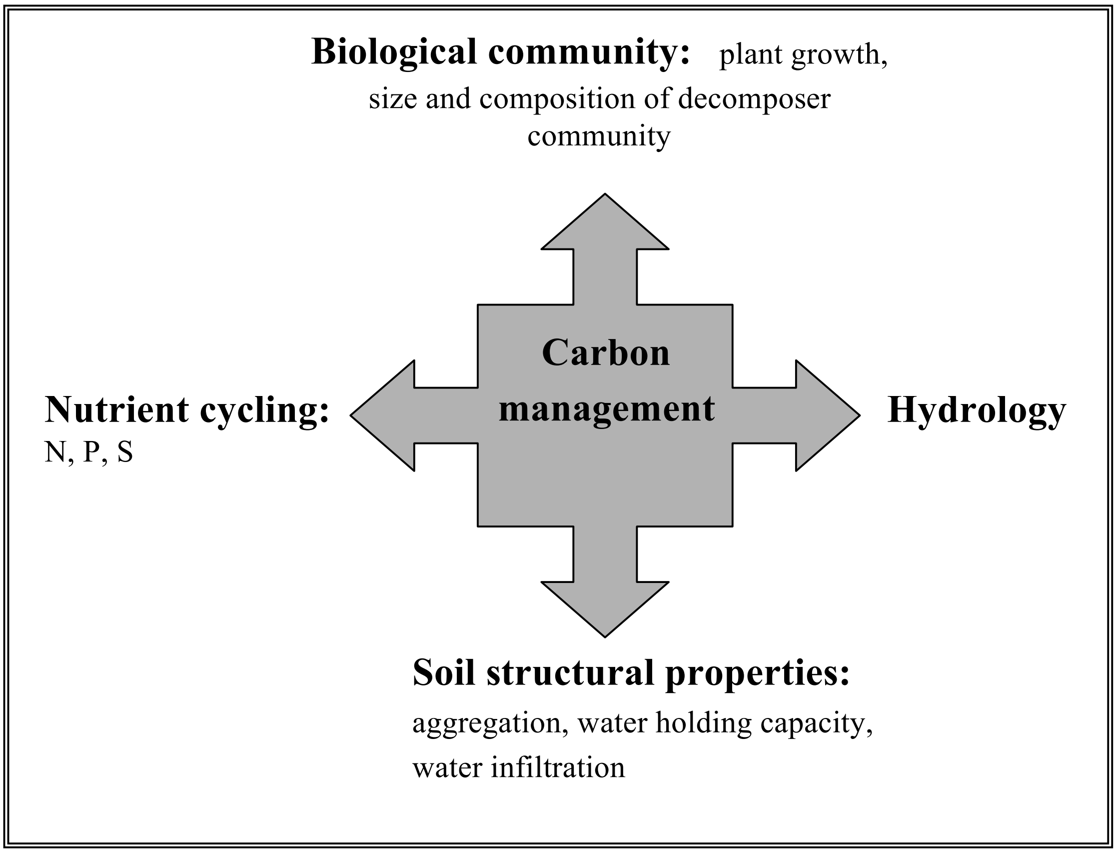

Figure 1 Carbon management plays a central role in agroecosystems.

Integrated rotation design must include other considerations such as weed suppression, and control of insect pests in addition to management of soil quality. In many cases, because of market demands the only flexibility in terms of including a mix of optimal plant species may be in the choice of auxiliary crops (non cash crops such as green manures, cover crops, crops for enhancing insect management). Although I will emphasise species impacts on below ground processes, these benefits will have to be considered along with other cropping system needs on a case-by-case basis.

Below ground net primary productivity is important

As a first step, rotations should be designed with the goal of maximising below ground net primary productivity (BNPP) in space and time. This simple strategy alone can have a major impact on both C retention and nutrient use efficiency, particularly in terms of reducing nitrogen (N) losses. Below ground productivity of auxiliary crops can be manipulated though plant species differences in BNPP and by optimising the timing of root activity.

Few quantitative data are available on BNPP, mainly because dynamic C inputs from root turnover/exudation are difficult to quantify and highly variable (Liljeroth *et al.,* 1994). Static determinations of root biomass are sometimes used to estimate below ground productivity, but they are only a partial indicator of C inputs and can be misleading in cases where dynamic processes predominate. Below ground inputs are generally assumed to parallel aboveground net primary productivity, even though the limitations of this approach are acknowledged (Schlesinger, 1991; Tate *et al.*, 1991; Zak *et al.*, 1994). Despite the limited information, the importance of root production and turnover on soil C and N fluxes has been widely recognised for some time, and recent studies now indicate that root-derived litter appears to play a more significant role in N and C cycling than litter from aboveground sources (Wedin and Tilman, 1990; Gale and Cambardella, in press; Puget and Drinkwater, submitted). Nevertheless, it is clear that species differences in root biomass can be significant with grasses generally having significantly greater root length densities than other crop species (Kuo *et al.*, 1997). Vegetable production systems in particular could benefit from the inclusion of auxiliary crops that have well-developed root systems in the rotation.

In addition to species differences that either increase or decrease the quantity of C inputs, expanding the time frame of root activity can have several benefits. Rotations should be designed so that plants are always present to take advantage of periods when primary productivity can occur. First, the time frame for C inputs from root turnover and exudates is expanded. Wander *et al.* (1994) proposed that the extended period of root activity in rotations with winter covers may be the most significant factor contributing to the increased net C sequestration observed in organic rotations. Secondly, available N released through mineralisation will be taken up by growing plants reducing N losses that can occur when excess nitrate accumulates. Studies of nitrate leaching under cover crops versus fallow have found significant reductions in nitrate leaching where cover crops are used (McCracken *et al.*, 1994). Finally, increasing the cover of actively growing plants can increase the rate of biological weathering of soil mineral components increasing the availability of various micronutrients (Bormann *et al.*, 1998). Use of multi-species cover crops can increase both NPP of the cover crop as well as improve N-scavenging efficiency (Tilman, 1999).

Qualitative plant species effects

For decades, a basic principle guiding SOM management has been that equilibrium levels of C and N are controlled by net inputs rather than by qualitative properties (Larson *et al.*, 1972; Rasmussen *et al.*, 1980; Havlin *et al.*, 1990; Paustian *et al.*, 1992; Gregorich, 1995) and while simple differences in BNPP are certainly important, recent evidence suggests that qualitative differences in plant species are more significant than indicated by these earlier studies (Drinkwater *et al.*, 1998; Gale & Cambardella, in press; Puget and Drinkwater, submitted). Plant species can impact SOM equilibrium through differences in the tendency to foster the formation of soil aggregates, biochemical composition of litter and through interactions with native SOM. Although our understanding of these qualitative aspects of plant-soil interactions is not fully developed, there is enough information to expect that choosing plant species with specific traits, for example, a species that enhances aggregate stability need to be considered in designing rotations. These characteristics need to be considered along with potential BNPP.

Small grains, such as barley and rye, and legumes tend to promote aggregation to a greater extent than many cash crops (Tisdall & Oades, 1979; Reid & Goss, 1981; Angers & Mehuys, 1988, 1989). Reid & Goss (1981) found that maize, tomato and wheat actually decreased aggregate stability while growth of perennial ryegrass and lucerne tended to increase it. This increased aggregate stability has been attributed to polysaccarhides produced in the rhizosphere (Reid & Goss, 1981) and increased fungal populations associated with these species (Tisdall & Oades, 1979; Haynes & Beare, 1997). Haynes & Beare (1997) compared two legumes (white clover and lupin) and four non-legumes (Italian ryegrass, prairie grass, barley, and wheat) and found that the two legume species resulted in unexpectedly high aggregate stability relative to their root biomass suggesting that there may be fundamental differences in the rhizosphere of leguminous vs. non-leguminous plants. Increased aggregation in the legumes appeared to be related to greater fungal hyphae length in aggregates. For example, although the total root mass was similar in wheat and lupin, a greater proportion of lupin root biomass was located in aggregates and fungal hyphal length in these aggregates was 4-fold greater than in aggregates from soil where wheat was growing (Haynes & Beare, 1997).

Species differences in composition of residues have significant effects on the short-term dynamics of biodegradation and have been well-characterised in numerous microcosm experiments. Overall decomposition rate of plant residues is positively correlated with the percentage of cold-water-soluble material (sugars, free amino acids and soluble minerals), and negatively correlated with C:N ratio, lignin content, and lignin:N ratio (Taylor *et al.*, 1989; Johansson, 1994; Prescott & Preston, 1994; Couteaux *et al.*, 1996). The pivotal role of litter quality in controlling decomposition, N mineralisation and humus formation in natural ecosystems is generally acknowledged (Wedin & Tilman, 1990; Hobbie, 1992; Couteaux *et al.*, 1995). These effects of individual plant species on ecosystem-level processes such as N mineralisation dynamics can be expressed in relatively short time periods in ecosystems consisting of native perennial plant species (Wedin & Tilman, 1990).

Significant differences in plant litter biochemical composition also contribute to improved retention of both C and N in agroecosystems (Drinkwater *et al.*, 1998). Research in our long-term experiment, the Farming Systems Trial, found that residue quality differences related to plant species had a significant impact on SOM equilibrium. Over the course of 15 years, there were significant differences in organic residue inputs and in soil C sequestration in the conventional (CNV) and organic systems. Quantitative differences in residues returned and N balances across agroecosystems did not account for the observed changes in soil C and N levels (Table 1). The conventional system had greater mean cumulative aboveground net primary productivity (ANPP, Table 1) and returned a greater amount of crop residues to the soil compared to the organically managed systems. The quantity of C inputs was not the major driving force affecting soil C storage in these cropping systems. Even though the manure-based (MNR) and conventional systems received equal amounts of C, only the MNR system showed a significant increase in soil C (Table 1). The legume-based system (LEG), with lower average C inputs from aboveground sources also showed an increase in soil C. In the CNV system, aboveground inputs were in the form of senescent, high C:N crop residues, whereas both organic systems had significant inputs of low C:N residues including leguminous green manures. Changes in the $\delta^{13}C$ natural abundance of soil C suggest that differences in plant species composition across cropping systems have contributed to differential retention of C and N. These results indicate that the use of low C:N organic residues to maintain soil fertility, combined with greater temporal diversity in cropping sequences increased the retention of both soil C and N.

Our results differ from those reported from several classical experiments conducted in agroecosystems have concluded that residue quality related to plant species difference has no significant effect on SOM equilibrium (Larson *et al.*, 1972; Rasmussen *et al.*, 1980; Paustian *et al.*, 1992; Hassink, 1995). These studies have been widely cited and have probably played a significant role in the development of C management strategies that focus on the quantity of aboveground biomass production rather than composition or source of residues. Several reported no differences in total SOM accumulation in treatments receiving straw versus leguminous residues (Rasmussen *et al.*, 1980; Paustian *et al.*, 1992; Hassink, 1995), however, the shoot residues were imported to these plots rather than being grown *in situ* eliminating important species differences in root litter quality. Given the greater impact of below ground C inputs, species differences may be expressed largely through differences in root/microbial/soil interactions.

Table 1 Cumulative C fixed by aboveground net primary productivity and C in residues returned to the soil during 1981-95 (cumulative Mg C ha^{-1} over 15 years). Net changes in soil C after 15 years are also given. Senescent residues are from crops and weeds. Residues incorporated as living plants were mainly legumes in the LEG system but were predominantly grasses in the MNR system. Numbers within a column followed by a different letter are significantly different at the 0.05 probability level (protected Scheffe's). Reprinted by permission from Nature (Drinkwater *et al.*) copyright (1998) Macmillan Magazines Ltd.

Cropping system	Net primary productivity	Plant residues returned			Manure input	Total organic residue input	Change in soil C 1981 to 1995
		Senescent	Living	Total			
MNR	69[a]	21	3,7	25[a]	19	44[b]	2,0
LEG	68[a]	31	7,5	39[b]	0	39[a]	6,6
CNV	75[b]	43	0,0	43[c]	0	43[b]	2,2 *

*There was no significant change in soil C over time in the CNV system (ANOVA, p>0.05).

Finally, actively growing roots can also effect C storage by either increasing or decreasing the mineralisation rate of native organic matter (Helal & Sauerbeck, 1986; Liljeroth *et al.*, 1990, 1994). The net effect of roots on mineralisation depends on plant species and soil environmental conditions such as N availability (Tate *et al.*, 1991; Liljeroth *et al.*, 1994). More information is needed in this area in order to identify those plant species and conditions that lead to net mineralisation of SOM.

Residue source effects: roots versus shoots

We have recently used in situ ^{13}C-labelling to trace the pathway of root-derived and shoot-derived C following incorporation of hairy vetch, a common leguminous green manure (Puget & Drinkwater, submitted). Although initially 3-fold more C originated from shoots compared to roots, at the end of the going season, equal amounts of shoot-derived and root-derived C remained in the top 20 cm of soil. A much greater proportion of shoot C had been lost during decomposition (85%) compared to root-derived C losses (50%; Puget & Drinkwater, submitted). Furthermore, the remaining root-derived particulate organic matter was disproportionately associated with aggregates suggesting that root litter played a more significant role than did shoot litter in aggregate promotion. Our results suggest that roots contribute to the improvement of soil tilth and water-holding capacity whereas shoots are more significant in supplying N to the cash crop.

Rotation-induced effects mediated by decomposers

Ultimately, SOM turnover is mediated by the decomposer community and, as we begin to understand the effects of management on the microbial community in terms of both physiological activity and species composition, it may be possible to foster communities that will optimise soil ecosystem function. In recent years several studies have shown labile SOM pools and microbial activity are increased in cropping systems based on organic soil amendments relative to those receiving mineral fertilisers (Bolton, 1985; Schnurer *et al.*, 1985; Anderson & Domsch, 1990; Wander *et al.*, 1994; Drinkwater *et al.*, 1995) however, it is not clear that this increased biomass necessarily leads to greater net retention of C. In addition to the quantitative changes in microbial biomass induced by various agricultural practices, changes in species composition and metabolic state C vs N limitation (dormant vs active) also occur (Anderson & Domsch, 1990; Workneh & van Bruggen, 1994; Bassio & Scow, 1995; Buyer & Drinkwater, 1997). We have shown in earlier studies that there are significant differences in microbial community structure and C source utilisation potential across these cropping systems (Buyer & Drinkwater, 1997). These management induced differences in microbial community structure could impact on numerous soil processes related to C and N cycling (Holland & Coleman, 1987; Anderson & Domsch, 1990).

Increased plant species diversity has been linked to greater energy use efficiency by the microbial community in agricultural systems (Anderson & Domsch, 1990). The C cycling characteristics of organically and conventionally managed soils in Farming Systems Trial differed in their response to acetate addition and in the sources of C metabolised (Wander *et al.*, 1996). In addition to differences in energy use efficiency, variations in the biochemical composition of soil organisms themselves can also influence C sequestration as the microbial biomass is decomposed. Using microcosm incubations Kassim *et al.* (1981) found that C originating from cells from differing microbial species was incorporated into different SOM pools. After 12 weeks of incubation 43% of whole cell C from both *Streptomyces halstedii* and *Micromonospora chalceae* remained in the soil, however twice as much C from *S. halstedii* had been incorporated into the microbial biomass.

Tillage rotation

In annual cropping systems, tillage intensity is a major determinant of soil C equilibrium levels (Buyanovsky *et al.*, 1987; Balesdent *et al.*, 1988; Cambradella & Elliot, 1992, 1994). Tillage generally reduces equilibrium SOM levels, by increasing the turnover rate of C that is structurally labile but physically protected (Balesdent *et al.*, 1988; Cambradella & Elliot, 1992, 1994). For this reason, systems with reduced tillage intensity tend to have greater levels of SOM (Paustian *et al.*, 1995).

In an effort to develop organic rotations with reduced tillage intensity, we have studied tillage options that alternated no-till with different forms of primary tillage in legume-based agronomic rotations. Treatments using primary tillage before planting of all crops (chisel disc: CD and mouldboard plough: MP) were compared to various treatments where maize was planted into hairy vetch using a no-till planter, the vetch was subsequently killed by mowing two weeks after maize planting. The most successful mixed tillage rotation used primary tillage before planting vetch planting followed by no-till maize with cultivation for weed control (CD-NTc). Properly timed surface disturbance though mechanical cultivation provided dual benefits: weed suppression and improved the timing of N mineralisation from green manure residues (Drinkwater *et al.*, submitted). Both the MP and CD treatments had extremely high levels of mineral N early in the season long before the maize crop required significant N (Figure 2). These large pools of mineral N, which consisted mainly of nitrate, could lead to significant nitrate leaching in years with rainy springs. In contrast, soil mineral N concentrations in no-till maize with cultivation (CD-NTc) never reached the levels seen in the treatments with incorporated vetch, thus reducing the potential for nitrate leaching. Planting no-till maize into the green manure mulch reduced mineralisation early in the season when plant uptake was also low (Figure 2). Later, surface cultivation stimulated mineralisation of the green manure at a time when maize was growing rapidly. Use of some tillage in seed-bed preparation for planting winter annual green manures increased the probability for successful stand establishment, however in the long-term leguminous green manure crops that can germinate under high residue/no-till conditions should be developed.

Conclusions

Clearly, manipulation of crop rotation and tillage can have a major influence on C and N cycles, nutrient retention, soil structure and many other aspects of soil quality that are related to SOM turnover. In general, the evidence suggests that managers should aim to maximise both temporal diversity and as well as the time span of plant growth and active roots in the rotation. Tillage should be used only as needed, based on field conditions at the time of planting including the type and amount of cover, soils moisture level and weed pressure. Differences in plant species characteristics, such as the amount of root production, contribution to N fertility, tendency to promote aggregate formation and biochemical composition of litter should be considered in selecting species to serve as cover crops. The lack of diverse plant species that can serve as cover crops and limited improvements in tillage implements are barriers to optimising organic cropping systems.

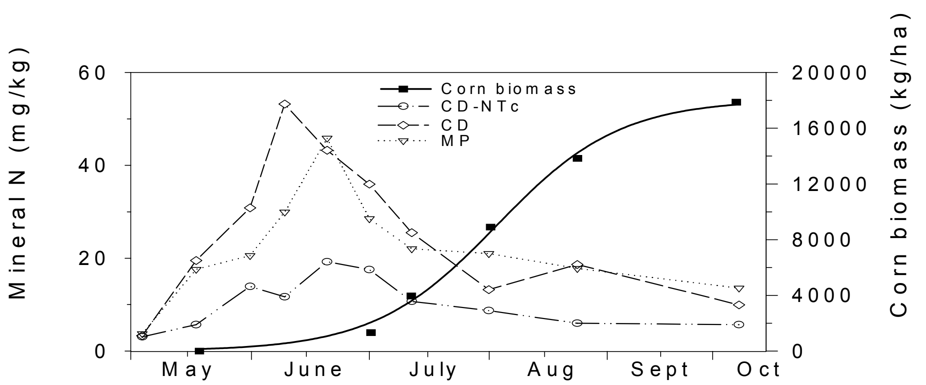

Figure 2 Mineral nitrogen concentrations at the 5-20 cm depth under three different tillage regimes during the growing season. Hairy vetch was incorporated either by either mouldboard ploughing (MP) or chisel discing (CD) prior to maize planting. In the CD-NTc treatment, corn was planted into the standing hairy vetch, which was then mow-killed at the end of May. Weed cultivation in all treatments occurred twice in June. Maize growth is shown for the MP plots.

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Long-term crop rotation experiments

Design of the Danish crop rotation experiment

J.E. Olesen[1], I.A.Rasmussen[2], M. Askegaard[1] and K. Kristensen[3]
[1] Department of Crop Physiology and Soil Science, P.O. Box 50, 8830 Tjele, Denmark
[2] Department of Crop Protection, Research Centre Flakkebjerg, 4200 Slagelse, Denmark
[3] Department of Agricultural Systems, P.O. Box 50, 8830 Tjele, Denmark

Summary

A field experiment is conducted which focuses on different aspects of crop rotations for cereal production in organic farming. Three factors are included in the experiment in a factorial design: A) fraction of grass-clover and pulses in the rotation (crop rotation), B) catch crop (with or without catch crop or bi-cropped clover), and C) manure (with or without animal manure applied as slurry). All courses in all rotations are present each year. The experiment is conducted at four locations, representing different soil types and climate regions in Denmark. The main design criteria were related to requirements for a long-term experiment and to the need of performing studies and experiments within the experiment itself.

Yield is measured in all plots at harvest, and total above ground biomass is determined at maturity and before field operations which incorporate plant material. The contents of nitrogen, phosphorus and potassium in the yield are measured. The occurrence of weeds, diseases and pests are recorded in all plots with cereals and pulses. Leaching of nitrogen and potassium is measured using porous ceramic cups in selected plots.

The experiment is designed as a factorial experiment with two replicates, where the three-way interaction is confounded with the sub-block effect. This is shown to increase the sensitivity of statistical tests of main effects and two-way interactions. The use of more than one measurement per plot also increases the sensitivity of the statistical tests.

Introduction

The crop rotation is a crucial and integral part of organic farming systems. It is the crop rotation as a whole that contributes to the farm outputs, and inputs of nutrients must also be supplied to the rotation as a whole for the maintenance of soil fertility. It is also the rotation as a whole and the associated management that determines the impacts on environment, e.g. through nitrate leaching.

The functioning of a crop rotation is not only determined by the sequence of crops in the rotation, but also by the management of the individual crops and of the rotation as a whole. The use of cover crops, fertilisers and control measures against weeds, pest and diseases are integral parts of the management of crop rotations.

Some of the most important rotational aspects of crop rotations for organic farming include:

- Green manure crops
- Winter or spring cereals
- Pulses and other legumes
- Row crops
- Cover or catch crops

The primary management options in organic crop rotations are:

- Manure (fertiliser) application
- Mechanical weed control
- Straw removal
- Soil tillage
- Harvest time, e.g. cereals for maturity or for whole crop silage

The performance of the systems is mainly affected through four main variables: nitrogen, weeds, other nutrients, and pests and diseases. This is measured through effects on yield, weed infestation, nitrogen leaching and production costs. The yield of a rotation may be measured either by the yield per unit sales crop area or per unit rotational area.

There has only been a limited number of studies under temperate conditions in Europe and North America, where different crop rotations have been compared under organic farming or similar production conditions. Examples of recent pure organic rotation trials are the comparison of stockless crop rotations at Elm Farm in England (Bulson *et al.*, 1996), and the rotations with different fractions of grass-clover ley in Scotland (Younie *et al.*, 1996). Other experiments have compared organic and integrated or conventional crop rotations. An example of this is the DOK experiment in Switzerland (Besson *et al.*, 1992). Other experiments have looked at the interaction between crop rotation and fertilisation level, e.g. in Norway (Uhlen *et al.*, 1994) and in Poland (Kus & Nawrocki, 1988).

This paper describes the structure of a crop rotation experiment, which is carried out at four sites in Denmark. The experiment focuses on the possibilities of short- and long-term increases in grain production in organic farming.

Materials and methods

The Danish crop rotation experiment is designed as a factorial experiment with three factors and two replicates where all courses of the rotations are present every year. The experimental factors are:

1. Fraction of clover grass and pulses in the rotation (crop rotation).
2. Catch crop (with/without catch crop or bi-cropped clover).
3. Fertiliser (with/without animal manure as slurry).
4.

Four different four-year crop rotations are compared. The contribution of different crop types in the rotations is shown in Table 1, and the actual rotations are shown in Table 2. The ranking of the crop rotations define a decreasing input of nitrogen through nitrogen fixation:

1. 1.5 grass-clover and 1 pulse crop.
2. 1 grass-clover and 1 pulse crop.
3. 1 grass-clover crop.
4. 1 pulse crop.

Table 1 Percentages of crop types in the four crop rotations. Autumn crop cover is defined as permanent white clover understories, grass clover leys, or catch crops of grass or grass clover.

Crop type	Rotation 1	Rotation 2	Rotation 3	Rotation 4
Green manure	25	25	25	0
Pulse	25	25	0	25
Spring cereal	50	25	25	25
Winter cereal	0	25	25	50
Row crop (beet)	0	0	25	0
Autumn crop cover				
without catch crops	50	25	25	0
with catch crops	100	75	50	100

Table 2 Crop rotations with and without catch crops. The sign ':' indicates that a grass-clover ley, a clover or a ryegrass catch crop is established in a cover crop of cereals or pulses. The sign '/' indicates a mixture of peas and spring barley or bi-cropping of winter cereals and clover.

Catch crop	Rotation 1	Rotation 2	Rotation 3	Rotation 4
Without	S. barley:ley	S. barley:ley	S. barley:ley	Spring oat
	Grass-clover	Grass-clover	Grass-clover	Winter wheat
	Spring wheat	Winter wheat	Winter wheat	Winter cereal
	Lupin	Peas/barley	Beet	Peas/barley
With	S. barley:ley	S. barley:ley	S. barley:ley	S. oat:clover
	Grass-clover	Grass-clover	Grass-clover	W. wheat/clover
	S. wheat:Grass	W. wheat:Grass	W. wheat:Grass	W. cereal/clover
	Lupin:Grass	Peas/barley:Grass	Beet	Peas/barley:Grass

The catch crop in rotations 1, 2 and 3 is either a pure stand of perennial ryegrass *Lolium perenne* or a mixture of perennial ryegrass and four clover species (hop medic *Medicago lupulina*, trefoil *Lotus corniculatus*, serradella *Ornithopus sativus* and subterranean clover *Trifolium subterraneum*). These catch crops are undersown in the cover crop in spring. The catch crop treatment in rotation 4 is a bi-crop of winter wheat in a pure stand of white clover (Askegaard *et al.*, 1999).

The fertilised plots are supplied with animal manure (slurry) at rates corresponding to 40% of the nitrogen demand of the specific rotation. The nitrogen demand, based on a Danish national standard (Plantedirektoratet, 1997) is 60, 60, 93 and 113 kg N ha^{-1} as an average of the fields in rotations 1, 2, 3 and 4, respectively. The nitrogen demands from grass-clover and from peas/barley are set to nil.

The experiment is carried out at four sites representing different soil types and climate regions in Denmark (Table 3). Not all rotations and treatments are carried out at all sites, but rotation 2 is present at all sites. The geographic location of the four sites is shown in Table 4.

Table 3 Experimental sites and treatments.

Location	Soil type	Irrigation	Replicates	Crop rotations	Fertiliser	Catch crop
Jyndevad	Sand	Yes	2	1+2	With/without	With/without
Foulum	Loamy sand	No	2	2+4	With/without	With/without
Flakkebjerg	Sandy loam	No	2	2+4	With/without	With/without
			2	3	With	With
Holeby	Sandy loam	No	1	2+3+4	With	Without

Table 4 Geographical location of the experimental sites.

Location	Latitude	Longitude
Jyndevad	9°08'E	54°54'N
Foulum	9°34'E	56°30'N
Flakkebjerg	11°23'E	55°19'N
Holeby	11°27'E	54°43'N

The experiment is unirrigated at all sites except Jyndevad, where the irrigation scheduling program MarkVand (Plauborg & Olesen, 1991) is used to define the irrigation demand. All straw and grass-clover production is incorporated or left on the soil in all treatments (Askegaard *et al.*, 1999).

Weeds in cereals and pulses without catch crops are mainly controlled by harrowing (Rasmussen *et al.*, 1999). Large weed plants (e.g. creeping thistle *Cirsium arvense* and mugwort *Artemisia vulgaris*) are controlled by manual weeding. The beets are kept weed-free by a combination of pre-emergence flaming, mechanical and manual hoeing, and the pulling up of large weeds. Couch grass (*Elymus repens*) if present is controlled by repeated harrowing after harvest in plots without catch crops. If the density of couch grass exceeds a threshold in any given year, the catch crop is omitted and mechanical weed control is performed in the autumn.

Local conditions can affect the plots differently, even at the same experimental site. This means that one of the two replicates of each treatment may have need for a management treatment (e.g. for controlling couch grass), whereas the other replicate has no need. Guidelines have therefore been set up defining the conditions under which the plots can be managed individually and when both replicates should be managed identically. If a management treatment changes the principle effect of one of the three experimental treatments (rotation, catch crop and manure) then both replicates should be managed identically. All other management treatments are based on the need of the individual plots.

Each plot is sub-divided into three to five sub-plots (Fig. 1). Two of the sub-plots are harvested for determination of crop yield. The other sub-plots are used for plant and soil sampling and for experiments. All samplings and some of the experiments are conducted in mini-plots, which are square plots of 1 m^2. The positions of the plots and of the mini-plots are fixed through use of permanently installed iron tubes in guard rows between all plots. The iron tubes are used for reference when managing the plots.

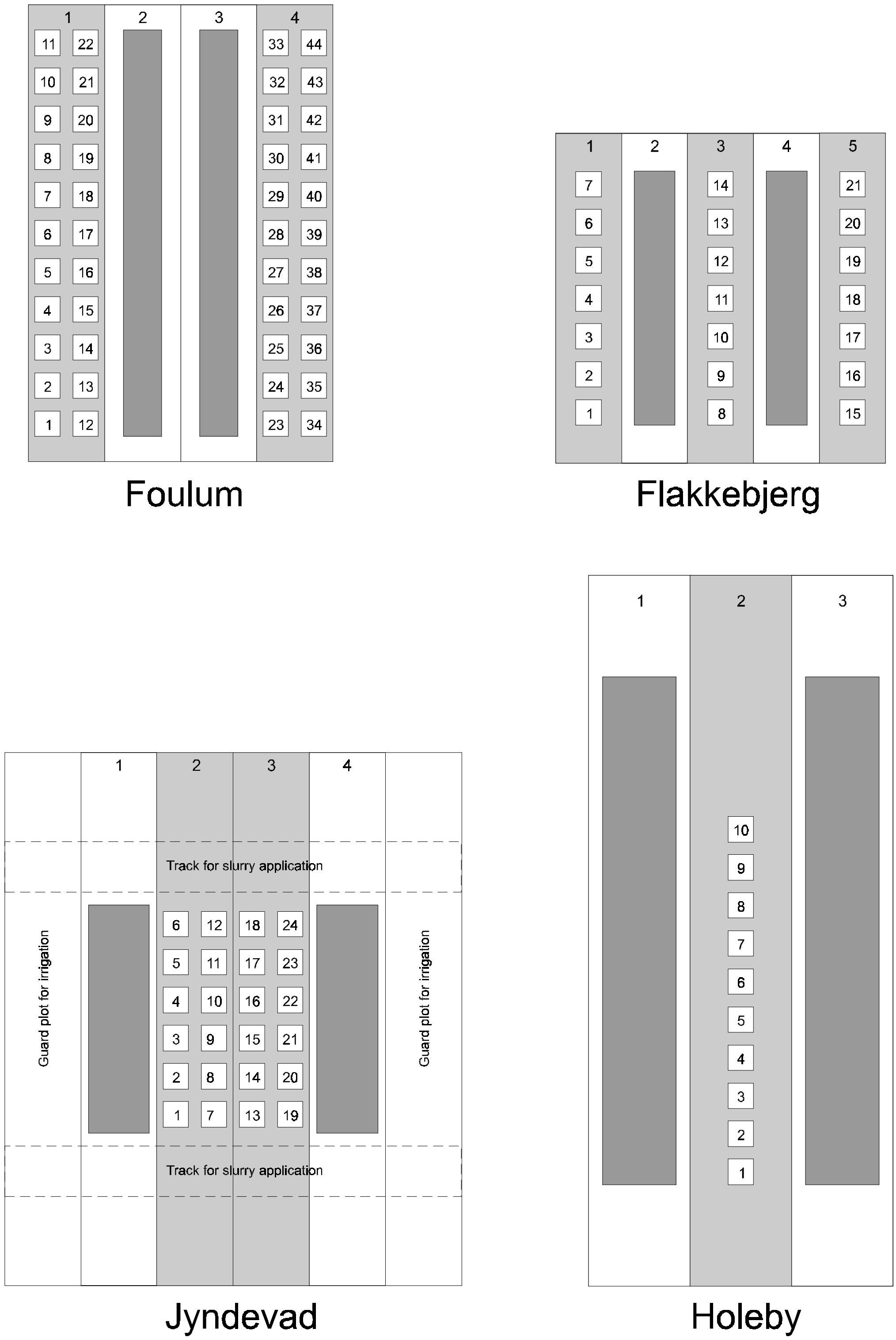

Figure 1 Plot infrastructure at the four experimental sites with sub-plots and mini-plots. Both sub-plots and mini-plots are numbered. The harvest parts of the plots are shown with a dark shade. The part containing mini-plots are shown with a light shade. The size of each mini-plot is 1 m^2. The width of sub-plots is 2.6 m at Flakkebjerg and 3 m at the other sites.

Short cut grass borders separate all plots in order to prevent movement of soil between plots. A soil border separate the crop of each plot from the grass border. This soil border is kept bare throughout the growing season by rotary cultivation in order to prevent weeds (e.g. couch grass *Elymus repens* and white clover *Trifolium repens*) from entering or leaving the plots and annual weeds from establishment and seeding.

A characterisation of the soil at the experimental sites was conducted in autumn 1996 prior to the initiation of the experiment. Sixteen soil samples to one meter depth were taken in each plot. The soil horizons of all soil samples were characterised using a standard soil taxonomy (Soil Survey Staff, 1992). The samples were divided into 25 cm layers, and the samples from each layer in the plot were mixed. The samples from all layers were analysed for pH and contents of K and P. Samples from selected plots and soil layers were also analysed for soil texture, cation exchange capacity (CEC) and total nitrogen. Soil pH was determined in a mixture of soil and a solution of 0.01 M $CaCl_2$. The soil pH was calculated as pH($CaCl_2$)+0.5. The content of K was determined after extracting the soil for 30 minutes with a solution of 0.5 M ammonium acetate. The content of P was determined after extracting the soil for 30 minutes with a mixture of 0.5 M $NaHCO_3$ and active carbon. The soil texture was determined as described by Plantedirektoratet (1994). The CEC was determined by the method described by Kalra & Maynard (1991). Total nitrogen was determined by the method described by Hansen (1989).

Yield is measured in all plots both at harvest and when incorporating plant material. The grain yield of cereals and pulses are measured at harvest maturity in two sub-plots in each plot using a combine harvester. The size of the net harvest plots varies between sites from 16 to 58 m^2. In addition two 0.5 m^2 samples of total aboveground biomass are taken from each plot at growth stage 85 (Lancashire *et al.*, 1991) in the cereal and pulse crops. The contents of nitrogen, phosphorus and potassium in the yield are measured. The soil content of mineral nitrogen is measured in spring. The occurrence of weeds, diseases and pests and nutrient deficiencies are recorded in all plots with cereals and pulses (Rasmussen *et al.*, 1999).

Leaching of nitrogen and potassium is measured using porous ceramic cups in selected plots. Four suction cells are permanently installed in each of these plots at a depth of 80 cm at Jyndevad and 100 cm at the other sites. The leaching is measured at all sites in those plots that corresponded to field one in the rotations when the experiment was initiated in 1997 (Table 2). This means that all crops in the rotations will subsequently be grown on the plots having these suction cells installed. At Foulum and Flakkebjerg leaching is additionally measured in all plots in rotation 2 without catch crops and with fertiliser. At Jyndevad leaching is measured in all plots with fertiliser. At Holeby leaching is measured in a total of six plots.

The treatments are carried out in two replicates (blocks) at all sites except at Holeby (Table 3). Each block is subdivided into two sub-blocks. The three-way interactions between crop rotation, catch crop and fertiliser treatments are confounded with the sub-blocks. The plots are randomised within each sub-block. None of the main effects or two-way interactions are confounded.

The practical result of the confounding of treatments can be illustrated at Foulum, where sub-block 1 has the treatment combinations; rotation 2 with catch crop and without fertiliser, rotation 2 without catch crop and with fertiliser, rotation 4 with catch crop and fertiliser, and rotation 4 without catch crop and without fertiliser. The other combinations are located in sub-block 2. From a statistical point of view this experimental design strengthens the tests of main effects and two-way interactions, whereas it is impossible to test the three-way interactions.

Measurements on individual crops within each year and site can be analysed using the following linear model in cases where there is just one measurement from each plot:

$$X_{rcfbs} = \mu + \alpha_r + \beta_c + \gamma_f + (\alpha\beta)_{rc} + (\alpha\gamma)_{rf} + (\beta\gamma)_{cf} + G_b + D_{bs} + E_{rcfbs} \quad (1)$$

where X_{rcfbs} is the measured variable in the plot with rotation *r*, catch crop *c*, fertiliser level *f* in sub-block *s* of block *b*. α, β and γ denote the fixed main effects of the treatments crop rotation, catch crop and fertiliser level, respectively. $\alpha\beta$, $\alpha\gamma$ and $\beta\gamma$ denote fixed effects of the two-way interactions between these treatments. *G*, *D* and *E* are random effects associated with blocks, sub-blocks and plots, respectively.

If there are two or more measurements in each plot, then the measurements can be analysed for individual crops in each year and site using the following linear model:

$$X_{rcfbsi} = \mu + \alpha_r + \beta_c + \gamma_f + (\alpha\beta)_{rc} + (\alpha\gamma)_{rf} + (\beta\gamma)_{cf} + G_b + D_{bs} + E_{rcfbs} + F_{rcfbsi} \quad (2)$$

where X_{rcfbsi} is measurement *i* in the plot with rotation *r*, catch crop *c*, fertiliser level *f* in sub-block *s* of block *b*. *F* denotes the random effects associated with the measurements within each plot.

The parameters of the models were estimated using the method of residual maximum likelihood (REML) (Searle *et al.*, 1992) using the Newton-Raphson algorithm implemented in the MIXED procedure of SAS, Statistical Analysis System (SAS Institute, 1996). The standard error of differences (s_e) between main effects was calculated as

$$s_e = \sqrt{2\left(\frac{\sigma_E^2}{n_m} + \frac{\sigma_F^2}{n_m n_r}\right)} \quad (3)$$

where σ_E^2 and σ_F^2 are variances associated with the random effects of plots and sub-plots/mini-plots, respectively. n_m is the number of plots with a given main effect within a sub-block, and n_r is the number of replicate measurements per plot.

Results and discussion

The results of the initial characterisation of the experimental sites are summarised in Tables 5 to 7. The mean clay content varies from about 4% at Jyndevad to about 24% at Holeby (Table 5). This variation is typical for the soil types in Denmark, where 24% of the agricultural area is occupied by coarse sandy soils represented by Jyndevad, 28% by loamy sands represented by Foulum, 24% by sandy loams represented by Flakkebjerg, and 6% by sandy loams and loams represented by Holeby (Madsen *et al.*, 1992). The remaining 18% of the Danish agricultural area is mainly occupied by soils with a high contents of organic matter or fine sand and by some silty or calcareous soils. The classification of the soils at the four sites is shown in Table 7.

The depth of the A-horizon varies between sites, and also considerably within sites (Table 7). The A-horizon is the upper soil horizon, which is influenced by tillage and which visibly has a larger humus content. The larger average depth of the A-horizon at Foulum and Flakkebjerg is largely caused by very deep A-horizons on parts of the experiment area. These two sites are also the only sites, where there is a consistent increase in clay content with increasing soil depth (Table 5). The content of organic matter in the plough layer is about twice as high at Foulum compared with the other sites. The organic matter content does, however, not decrease as rapidly with depth at Flakkebjerg and Holeby as at Jyndevad and Foulum. This indicates considerably deeper rooting on the sandy loam soils.

Table 5 Soil texture at the four sites at different depths. Particle size fractions, organic matter and calcium carbonate in percent of dry soil.

Horizon (cm)	Clay < 2 μm	Silt 2-20 μm	Fine sand 20-200 μm	Coarse sand 200-2000 μm	Organic matter	$CaCO_3$
Jyndevad						
0-25	4.5	2.4	18.0	73.1	2.0	-
25-50	4.4	1.3	16.6	76.7	1.1	-
50-75	3.8	0.7	14.7	80.3	0.4	-
75-100	4.3	0.8	16.1	78.6	0.3	-
Foulum						
0-25	8.8	13.3	47.0	27.2	3.8	-
25-50	11.2	12.9	46.2	27.6	2.1	-
50-75	13.5	11.9	47.0	26.8	0.7	-
75-100	14.4	11.3	46.4	27.5	0.4	-
Flakkebjerg						
0-25	15.5	12.4	47.4	22.9	1.7	0.1
25-50	17.2	12.6	46.7	21.7	1.1	0.6
50-75	19.0	12.1	45.5	20.9	0.6	1.8
75-100	19.4	11.9	44.1	20.5	0.4	3.9
Holeby						
0-25	24.0	24.0	35.2	14.7	2.2	-
25-50	23.3	26.2	32.3	16.5	1.7	-
50-75	22.9	27.1	35.5	13.5	1.1	-
75-100	17.8	24.1	37.9	19.3	0.9	-

The high organic matter content at Foulum causes the CEC here to be just as high as the CEC at Flakkebjerg (Table 6), despite the differences in clay content. The soil pH is highest on the two sandy loam soils, but the content of plant available P is lowest here, especially at Holeby. The content of plant available K is quite low at Jyndevad, indicating that potassium deficiency may become a problem on this coarse sandy soil.

The climatic differences are modest across Denmark due to the low relief, but there are some differences between the sites in temperature, precipitation and potential evapotranspiration (Table 8). The mean annual temperature is almost 1°C higher at Holeby compared with Foulum. This covers roughly the span of mean normal temperatures obtained in Denmark. The average annual precipitation varies from 626 mm at Flakkebjerg to 964 mm at Jyndevad. This covers most of the spatial variation in rainfall in Denmark. The spatial variation in potential evapotranspiration is much smaller.

Table 6 Mean values of chemical analyses of the soils at the four sites at different depth for samples taken in autumn 1996. pH is taken as pH($CaCl_2$)+0.5. P and K are measured as mg per 100 g dry soil. Cation exchange capacity (CEC) is measured as meq per 100 g dry soil. Organic C and total N is measured in percent of dry soil.

Horizon (cm)	pH	P	K	CEC	Organic C	Total N
Jyndevad						
0-25	6.1	5.2	4.9	8.0	1.17	0.085
25-50	5.9	1.0	2.6	5.6	0.62	0.041
50-75	5.6	0.4	2.6	4.3	0.25	0.017
75-100	5.3	0.3	2.9	4.6	0.14	0.016
Foulum						
0-25	6.5	5.4	13.1	12.3	2.29	0.175
25-50	5.9	2.2	6.8	10.1	1.25	0.094
50-75	5.2	1.5	7.1	7.8	0.43	0.041
75-100	4.8	1.3	7.9	7.6	0.21	0.026
Flakkebjerg						
0-25	7.4	3.0	9.8	10.6	1.01	0.107
25-50	7.5	1.7	6.9	10.5	0.67	0.074
50-75	7.5	0.7	6.6	10.5	0.34	0.042
75-100	7.8	0.4	6.8	10.3	0.21	0.032
Holeby						
0-25	8.0	1.2	10.4	17.0	1.56	0.139
25-50	8.0	0.8	8.0	13.5	1.03	0.103
50-75	8.1	0.4	6.4	9.7	0.48	0.043
75-100	8.2	0.3	5.6	7.4	0.55	0.023

Table 7 Mean depth of the A-horizon formed at the soil surface, and classification of the soils according to the Soil Taxonomy System (Nielsen and Møberg, 1985). The values in brackets are standard deviations.

Location	Soil classification	Depth of A-horizon (cm)
Jyndevad	Orthic Halplohumod	32 (6)
Foulum	Typic Hapludult	44 (14)
Flakkebjerg	Typic Agrudalf	45 (16)
Holeby	Oxyaquic Hapludalf	35 (6)

The effect of the experimental design on the statistical tests of the main and two-way interaction effects on grain yield and total biomass at growth stage 85 was analysed using data from first year winter wheat and from pea/barley in rotations 2 and 4 at Foulum and Flakkebjerg in 1998, and spring barley from rotations 1 and 2 at Jyndevad in 1998. The data was analysed using either model (1) or (2).

The estimated variance components for the random effects in model (2) are shown in Table 9. The variance components were almost exclusively allocated to the plot and sub-plot effects at Flakkebjerg, whereas some of the random variation at Jyndevad and Foulum was allocated to blocks and sub-blocks. The variance components were also much higher at Flakkebjerg compared with the other two sites.

The estimated effect of number of replicate measurements of yield and total biomass per plot on the standard error of difference between main treatments is shown in Table 10. The reduction in standard error with increasing number of replicates was largest where most of the random variation was attributed to the sub-plot level. The effect of including sub-blocks on the standard error was generally small and not always present.

Table 8 Average monthly and annual air temperature, precipitation and potential evapotranspiration at Jyndevad (Jy), Foulum (Fo), Flakkebjerg (Fl) and Holeby (Ho) for the period 1961-90 (Olesen, 1991). The normal climate for Holeby was taken from the station at Abed. The precipitation is corrected to ground level, and the potential evapotranspiration was calculated using a modified Priestly-Taylor formula.

	Temperature (°C)				Precipitation (mm)				Pot. evapotrans. (mm)			
Month	**Jy**	**Fo**	**Fl**	**Ho**	**Jy**	**Fo**	**Fl**	**Ho**	**Jy**	**Fo**	**Fl**	**Ho**
January	0.1	-0.5	-0.4	-0.1	83	43	48	58	6	5	5	6
February	0.3	-0.5	-0.4	0.0	50	34	31	44	12	12	12	12
March	2.7	1.8	1.9	2.4	66	48	39	47	28	28	29	29
April	6.2	5.5	5.8	6.3	53	40	39	50	54	54	56	57
May	11.0	10.5	11.0	11.4	62	50	49	48	88	86	93	93
June	14.4	14.2	14.6	15.1	73	57	51	55	99	103	107	106
July	15.7	15.4	15.9	16.3	84	72	64	74	96	98	102	104
August	15.7	15.1	15.9	16.3	89	71	60	66	84	83	88	88
September	12.9	12.1	12.9	13.3	98	75	65	62	49	48	52	53
October	9.3	8.5	9.2	9.5	108	76	59	55	25	23	26	27
November	4.8	4.2	4.7	5.1	112	78	62	73	9	9	10	11
December	1.5	1.1	1.5	1.8	89	61	59	64	5	4	5	5
Year	**7.9**	**7.3**	**7.8**	**8.2**	**964**	**704**	**626**	**694**	**554**	**553**	**586**	**590**

The standard error was about 5 times higher for total biomass compared with grain yield. This is due to the higher sample area for measuring grain yield. The standard error of biomass estimated was about twice as high at Flakkebjerg compared with Foulum, indicating that the small-scale spatial variability is highest at Flakkebjerg. The standard error of grain yields was about three times as high at Flakkebjerg compared with Foulum, which is caused both by the higher small scale variability at Flakkebjerg and the smaller harvest plots used at Flakkebjerg compared with Foulum. The harvest plots at Foulum and Jyndevad are of similar size, but the standard error was considerably larger at Jyndevad compared with Foulum. The site at Foulum thus seems to have the most homogeneous soil of these three sites.

Table 9 Estimated variance components in model (2) for first year winter wheat, spring barley and pea/barley in 1998. σ_G^2, σ_D^2, σ_E^2 and σ_F^2 are variance components for random effects associated with blocks, sub-blocks, plots and sub-plots/mini-plots, respectively.

	Yield				Above ground biomass			
Location	σ_G^2	σ_D^2	σ_E^2	σ_F^2	σ_G^2	σ_D^2	σ_E^2	σ_F^2
First year winter wheat								
Foulum	695	75	0	309	0	5171	0	7245
Flakkebjerg	0	0	0	2770	0	0	8016	19338
Spring barley								
Jyndevad	99	0	0	860				
Pea/barley								
Foulum	0	111	157	91	590	0	0	9832
Flakkebjerg	0	98	857	780	0	0	3907	18201

There were two main considerations in the design of the experiment. The first consideration was related to the wish to continue all or some of the treatments for a long time period. In order to investigate the effects of the systems on soil fertility the experiment should probably be run for at least three rotations, i.e. twelve years. The second consideration was caused by the requirement to perform other experiments and investigations within the framework of the experimental design, thus investigating the effects of the experiment treatments on dynamics of both soils and plants, and related effects on management.

The requirement for a long-term experiment called for measures to eliminate soil and substance movement between plots, which can otherwise have considerable effect on the treatment effects (Sibbesen, 1986). The plots are therefore separated by both continuous vegetation and continuous bare soil. This mixture ensures that neither soil nor weeds move between plots. There were also other management considerations that need to be considered. All management treatments and all measurements are performed with reference to fixed positions placed in the permanent vegetation between the plots. Ploughing is performed starting at the opposite side of the plots compared with the last ploughing operation in order to prevent permanent movement of soil in the plots.

There is a side effect to this fixed position of all operations. The traffic by tractors and other vehicles always occur on exactly the same parts of the plots. This may over time cause soil compaction in these strips. Measures are therefore taken to loosen the soil in connection with some of the tillage operations.

The sub-division of plots into sub-plots and mini-plots enables experiments and studies to be performed within the systems. The basic requirement for experimental treatments to be carried out in either sub-plots or mini-plots is that they do not have long-term effects on the functioning of the systems. The supplementary experiments carried out in 1999 in the crop rotation experiment included studies on addition of potassium and sulphur on crop yield and quality, and studies on competition between pea and barley in the pea/barley mixture depending on soil fertility.

Table 10 Standard error of difference between main treatments on dry matter grain yields and total biomass (g m^{-2}) for different number of replicate measurements per plot of yield and biomass. The estimates are shown with (+) and without (-) inclusion of random effects of sub-blocks in the statistical models.

Location	Sub-blocks	Replicates per plot	Standard error of treatment difference	
			Grain yield	Total biomass
First year winter wheat				
Foulum	+	1	8.8	42.6
	+	2	6.2	30.1
	+	3	5.1	24.6
	-	2	6.9	39.4
Flakkebjerg	+	1	26.3	82.7
	+	2	18.6	66.5
	+	3	15.2	60.1
	-	2	18.6	66.5
Spring barley				
Jyndevad	+	1	14.7	
	+	2	10.4	
	+	3	8.4	
	-	2	10.4	
Pea/barley				
Foulum	+	1	7.8	49.6
	+	2	7.1	35.1
	+	3	6.8	28.6
	-	2	8.9	35.1
Flakkebjerg	+	1	20.2	74.3
	+	2	17.7	57.0
	+	3	16.7	49.9
	-	2	18.3	57.0

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Agronomic considerations and dilemmas in the Danish crop rotation experiment

M. Askegaard[1], I.A. Rasmussen[2] and J.E. Olesen[1]
[1] Department of Crop Physiology and Soil Science, P.O. Box 50, DK-8830 Tjele, Denmark
[2] Department of Crop Protection, Research Centre Flakkebjerg, DK-4200 Slagelse, Denmark

Summary

Many agronomic factors have to be considered in the design and management of a long-term crop rotation experiment. Several factors and their interactions must be included in these considerations. Among the key factors are the crops, the weeds and the N-level in the soil. A tight interaction between these three factors has caused several dilemmas in the design and management of the crop rotation experiment carried out at four sites in Denmark. The management plan of the rotations is presented and examples of the most important dilemmas are given. Many questions have been raised where no answers can currently be given. Some of the central questions are listed.

Introduction

The design and management of organic crop rotations involves many considerations. Contrary to the conventional crop production where the management factors can be optimised individually (e.g. fertilisation or weed control), many factors and their interactions must be included in the design and management of organic crop rotations. The main reason for this is that the crop management of organic crop rotations must focus on the prevention of problems like diseases, pests and weeds, rather than the curing of problems. This prevention is based on the construction of sound crop rotations, which are able to reduce the propagation of diseases and on nitrogen self-sufficiency through the use of N_2-fixing crops. Another very important prevention factor is crop establishment, where a uniform seedbed and the right time of sowing preconditions good crop growth and development, which will improve its competitive ability against weeds.

When the effect of a possible management treatment, e.g. weed harrowing, is to be estimated, not only the weed infestation but also the crop and the nutrient-level in the soil must be considered. These three factors interact strongly. It is, however, difficult to use the current general knowledge about these interactions in the optimisation of crop management on a rotational basis.

This paper describes the practical management of a long-term crop rotation experiment carried out at four sites in Denmark, and the rationale behind this.

Material and methods

Four different four-year crop rotations are designed and tested with and without catch crops and with and without manure application (Table 1). The design of the crop rotation experiment is described in Olesen *et al.* (1999). At the start of the experiment a comprehensive guide to the practical management of the rotations was produced. This guide, which is revised every year, describes all procedures from choice of varieties to ploughing of the field. The prevailing conditions such as soil type, climate and machinery must always be included in the management decisions. The cereal crops as well as pea/barley and lupins are harvested at maturity. The grass-clover fields are used for green manure. During the growing season the grass-clover is cut several times and, similar to the straw, it is chopped and left on the ground in the field.

Table 1 Crop rotations with and without catch crops. The sign ':' indicates that a grass-clover ley, a clover or a ryegrass catch crop is established in a cover crop of cereals or pulses. The sign '/' indicates a mixture of peas and spring barley or bi-cropping of winter wheat and clover.

	Rotation 1	Rotation 2	Rotation 3	Rotation 4
Locations	Jyndevad	Jyndevad	-	-
	-	Foulum	-	Foulum
	-	Flakkebjerg	Flakkebjerg	Flakkebjerg
	-	Holeby	Holeby	Holeby
Without Catch crop	S. barley:ley	S. barley:ley	S. barley:ley	Spring oat
	Grass-clover	Grass-clover	Grass-clover	Winter wheat
	Spring wheat	Winter wheat	Winter wheat	Winter cereal
	Lupin	Peas/barley	Beet	Peas/barley
With Catch crop	S. barley:ley	S. barley:ley	S. barley:ley	S. oat:clover
	Grass-clover	Grass-clover	Grass-clover	W. wheat/clover
	S. wheat:Grass	W. wheat:Grass	W. wheat:Grass*	Winter cereal/clover
	Lupin:Grass*	Peas/barley:Grass*	Beet	Peas/barley:Grass*

* The catch crop is a mixture of ryegrass and four clover species.

Species and varieties

The rotations are designed for the production of cereal grains and pulses, and care has been taken to prevent diseases being favoured by the crop rotation. Peas (pea/barley) and lupins alternate from one rotation period to the next. In rotation 4 oat is grown prior to winter wheat in order to minimise the risk of infection with the take-all disease (*Gaeumannomyces graminis*). Triticale has been chosen as the second year winter cereal instead of winter wheat on the sandy soil at Foulum in order to reduce the problems with take-all.

The choice of varieties is made every year on the basis of a set of prioritised criteria. Using these we ensure that the varieties used are always the "best". Typically high potential yield is given less weight than other criteria such as disease resistance. We normally prefer varieties, which have been tested in Denmark for at least 2-3 years. In Table 2 some examples of these criteria are given.

The grass-clover in rotations 1, 2 and 3 is either a stand of white clover (*Trifolium repens)* and five varieties of perennial ryegrass (*Lolium perenne)* on the lighter soils (Jyndevad and Foulum) or the same mixture combined with red clover (*Trifolium pratense*) on the heavier soils (Flakkebjerg and Holeby). Red clover can be an aggressive competitor in the spring barley cover crop on lighter soils.

Table 2 Examples of criteria for variety choice.

Crop	Criteria
Winter wheat	1. High resistance against yellow rust
	2. Good resistance against other diseases
	3. Good winter hardiness
	4. High yields
	5. Tall/good competition against weeds
Spring oat	1. Resistance against nematodes
	2. High yields
Peas	1. High yield
	2. Tall crop canopy at harvest

The catch crops in rotations 1, 2 and 3 are either pure stands of late perennial ryegrass or mixtures of late perennial ryegrass and four clover species (hop medic *Medicago lupulina*, trefoil *Lotus corniculatus*, serradella *Ornithopus sativus* and subterranean clover *Trifolium subterraneum*). Pure stands of ryegrass are undersown in cereals where the previous and the following crop is N_2-fixing (Table 1). In all other cases the ryegrass-clover mixture is used.

Sowing

The crop establishment process is fundamental for the final crop yield. The sowing of spring cereals, peas and lupins is therefore carried out as early in the spring as possible, but not before a good preparation of the soil can be performed. The ploughing and the succeeding seedbed harrowing must be very uniform to allow the seeds to be placed at the correct depth and for the weed harrowing to be performed at uniform intensity. The winter cereals are sown the first time a proper seedbed can be prepared after 25 August. This is a little later than conventionally grown cereals in order to prevent dense weed stands developing in autumn.

All the catch crops and the grass-clover mixture are sown in the spring. In the spring cereals the sowing takes place the same day as the cover crop is sown, except for Jyndevad where delayed sowing is used in order to carry out some weed harrowing in the rotations with catch crops. Delayed sowing is possible in Jyndevad because the use of irrigation ensures the germination of the catch crops. In the winter cereals the catch crop is sown in April just after the first weed harrowing.

Application of slurry

In the treatments with application of manure the four different locations are allowed to use the predominant type of slurry available at the site. We therefore use pig-slurry and cattle-slurry as well as degassed slurry. The fertilisation plan is shown in Table 3 where the amounts of ammonia-N correspond to the ammonia content in the applied slurry. The application corresponds to 40% of the nitrogen demand of the specific rotation according to Danish national standards (Anonymous, 1997). The nitrogen demand of grass-clover and pea/barley are set at nil. The slurry is distributed equally between all non-fixing crops in rotations 1 to 3. In rotation 4, however, the winter cereals are favoured at the expense of oat.

Table 3 The fertilisation plan (kg NH_4-N ha^{-1}) for treatments with and with out catch crops.

Rotation 1		Rotation 2		Rotation 3		Rotation 4	
S. barley:ley	50	S. barley:ley	50	S. barley:ley	50	Spring oat	40
Grass-clover	0	Grass-clover	0	Grass-clover	0	Winter wheat	70
Spring wheat	50	Winter wheat	50	Winter wheat	50	Winter cereal	70
Lupin	0	Peas/barley	0	Beet	50	Peas/barley	0
Average	24		24		37		45

In order to obtain a uniform distribution of the slurry to spring cereals it is applied in the seedbed after ploughing and harrowing instead of before ploughing, which is the normal procedure used in practice. Immediately after application an additional harrowing is performed in order to minimise the ammonia volatilisation. In winter cereals slurry is applied in mid April at growth start using trail hoses. Where a broader row distance is used in the winter cereals the slurry is placed as close to the rows as possible in order to fertilise the cereals more than the weeds.

In all cereals the soil surface is loosened by harrowing just before slurry application. This accelerates the infiltration and prevents an uneven penetration of the slurry into the soil.

Weed management
Weeds in cereals and pulses without catch crops are mainly controlled by harrowing. Large weed plants (e.g. creeping thistle *Cirsium arvense*) are controlled by manual weeding. The beets are kept weed-free by a combination of pre-emergence flaming, mechanical and manual hoeing, and the pulling up of large weeds. Couch grass (*Elymus repens*) if present is controlled by repeated harrowing after harvest of crops without a catch crop. If the density of couch grass exceeds a threshold in any given year, the catch crop is omitted and mechanical weed control is performed in the autumn. Winter cereals without a catch crop are sown at a larger row distance in rotation 4 at Foulum to facilitate mechanical hoeing. At Jyndevad this procedure is used in all cereal crops without catch crop or undersown grass-clover and also in lupins without catch crop. As mentioned above, a delayed sowing of the catch crops at Jyndevad makes it possible to carry out some weed harrowing. A more comprehensive description of the weed management is given in Rasmussen *et al.* (1999).

Winter wheat and white clover in rotation 4
In rotation 4 with catch crops the catch crop is a pure stand of white clover. The white clover is undersown in oat. After harvest in the autumn and a few days before winter wheat sowing the clover is cut down as close to the soil surface as possible, followed by rotary cultivation in bands at double normal row spacing (25 cm). The winter wheat is drilled into these bands. The white clover is controlled during the growing season by cutting it separately with a brush weeder in order to reduce competition with the wheat. After harvest of the winter wheat the clover is allowed to grow and then again a few days before sowing the same procedure is repeated for the establishment of the second year winter cereal.

Management and decisions
In an experiment such as this where many decisions must be taken prior to and during each growing season and where four locations are represented, each with its own technical staff, the success of the experiment is highly dependent on a close co-operation between the technical and scientific staff and between the locations. This co-operation has included one winter meeting and one summer meeting

every year for the whole staff, meetings in the technical and the scientific groups and a close follow-up during the season.

Results and discussions

Adjustments of the rotations and management

The management of the rotations described above is the result of a continuing proces with many discussions between the project participants. From the start of the project in 1997 until now we have made some adjustments in both the design of the rotations and in the management. Our policy is, that as long as we do not interfere with the three key factors (see Olesen *et al.*, 1999) improvements to the rotations and management are permitted. After 1997 rotation 1 in Jyndevad was changed from barley, 1st year grass-clover, 2nd year grass-clover, winter wheat to the one presented in Table 1. The reason for this was that crop rotations with a high level of grass-clover already had proved their sustainability (Askegaard *et al.*, 1999). The change made it possible to compare spring wheat in rotation 1 to winter wheat in rotation 2, both following grass-clover and also to compare the pulse crops, lupins in rotation 1 with pea/barley in rotation 2. In 1998 we introduced more clover in the rotations in order to increase both the N_2-fixation and the diversity. Red clover was added to the grass-clover fields of the heavier soils and four clover species (described above) were mixed with the ryegrass-catch crop and used in selected crops. From 1999 slurry was applied to winter cereals in mid April instead of, as earlier, at the start of May. From the colour and growth rate of the winter wheat in the spring it was clear that even following a grass-clover crop, the wheat suffered from N-deficiency at the beginning of the growing season. The row distance was increased at Jyndevad and Foulum in selected crops without catch crops in order to improve the weed control by mechanical hoeing. A successful establishment of the white clover is a prerequisite for the success of rotation 4 (with catch crop). Oat undersown with pure white clover showed a vigorous growth at Foulum in 1997 and 1998. The plant density was therefore reduced in 1998 (from 400 to 300 germinating grains m^{-2}) and in 1999 we increased the row distance of the oat in order to increase the penetration of light to the clover. In order to increase yields triticale was introduced as the second winter cereal in rotation 4 in 1999 instead of winter wheat.

Dilemmas

In the planning of the crop rotations and their management we often came across situations where the factors we wanted to optimise were counteracting each other. The crop-weed-nitrogen triangle was often the reason for this. Figure 1 illustrates the triangle and the management options.

We have increasing problems with couch grass at Jyndevad. To control it we may perform repeated harrowing after harvest of the crops even in the rotations with catch crop. The dilemma is that nutrient leaching increases when the soil is bare. If leaching losses increase, the crop growth may be reduced the following year and the weed propagation may increase. In order to postpone the problems we have decided to carry out more frequent cuts in the grass-clover fields and in this way reduce the build-up of couch grass.

Another example of a dilemma is the way we establish the catch crops. The catch crops are typically sown at the same time as the cover crop. In this way we maximise the chances of having a well-established catch crop in the autumn and winter, which is able to reduce leaching losses. If the spring establishment fails we can have another try after harvest. Prioritising the catch crop in this way may, however, reduce yield and there is a risk of weed propagation because harrowing is not possible.

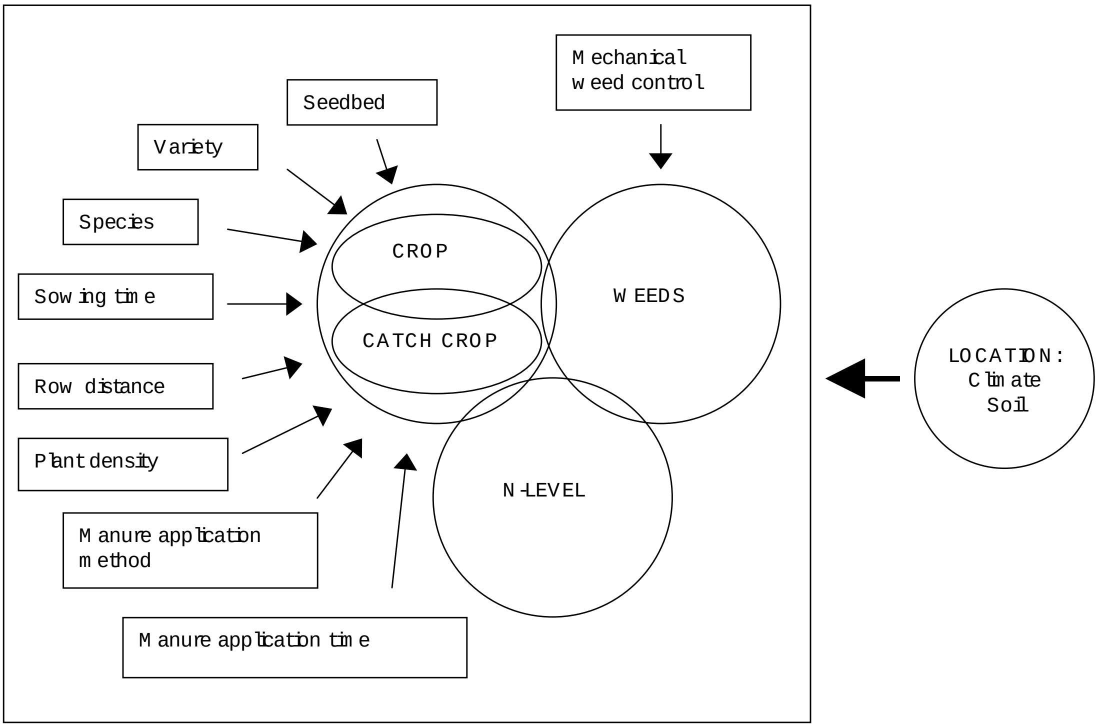

Figure 1 Interactions between crop, weeds and N-level and the management measures.

Decisions about whether a weed harrowing should be carried out after emergence of the crop or not may lead us into dilemmas because a weed harrowing can damage the crop, especially if the plants are weak or sparsely distributed in the rows. A choice often has to be made between the short-term protection of the crop against mechanical damage and the weed regulation, which may have long-term consequences. In the rotations with no manure application we have considered reducing the plant density in order to increase grain weight. This may however increase the risk of crop damage from the harrowing, because a sparse or weak crop is easily covered with soil when harrowing is performed.

Research needs sometimes counteracts with the best cropping practice. As an example we use pure cereal varieties instead of a variety mixture, because it makes it easier to register attacks of diseases. This procedure, however, may reduce the yield results from e.g. Flakkebjerg and Holeby relative to Jyndevad and Foulum because of a climatically induced higher infection risk at Flakkebjerg and Holeby.

Questions which need to be answered

- Which weed species can be tolerated in the different systems? What are the thresholds for weed harrowing? The knowledge must be coupled to different N-levels and different crop competitive abilities.
- In which way do we obtain the best utilisation of the grass-clover for green manure? This concerns both the treatments in the growing season (number and intensity of cuts) and the N-release to the succeeding crop.
- How often can the clover species be grown considering the risk of propagation of diseases in clover, and do different clover species share the same diseases?

- The pea fraction of the harvested pea/barley mixture is lower at Holeby compared with Jyndevad and Foulum. This may be caused by a higher N-level in the soil and possibly restriction of root growth in the soil at Holeby. How can we increase the production of pulses at Holeby?
- Can the protein content of the cereals be increased?
- Which strategy can control couch grass? This question includes the combined effect on crop yield and N-level.
- What are the effects of the different systems on soil compaction? How will the plant production be influenced in the long-term in systems with different degrees of compaction?
- The inter-cropping of winter cereal and white clover in rotation 4 needs to be improved. The main problem is probably N-deficiency and partly take-all. What can be done in order to improve the N-release to the winter cereal?
- The policy on the rotation experiment is that nutrients other than N must not be yield- limiting. When a limitation is detected the actual nutrient shall be applied. Which criteria and methods can be used to determine yield limitation? The standard soil test methods for P and K are probably incapable of predicting a yield-limiting deficiency.
- How do we increase the success of establishment of cover crops, especially legume cover crops?
- How should the manure be distributed between different crops in the rotation?

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Ten years experience of all-arable rotations

L. Philipps[1], J.P. Welsh[2] and M.S. Wolfe[1]
[1] Elm Farm Research Centre, Hamstead Marshall, Newbury, Berkshire, RG20 0HR, U.K.
[2]Current address: School of Agriculture Food & Environment, Cranfield University, Silsoe, Bedfordshire, MK45 4DT, U.K.

Summary

Organic farming systems are often perceived to require both livestock and crop production enterprises to form a viable agronomic and economic unit. However, there may be economic and other constraints which prevent specialist arable farmers considering converting to organic production methods. Should these constraints restrict conversion?

The stockless research programme was established by Elm Farm Research Centre (EFRC) in 1987. The programme was initiated to address the challenge of how conventional arable farms may convert to predominantly arable or stockless organic systems. This paper traces the development of all-arable or stockless systems in the UK. It examines how the research programme was developed using the experience of organic advisers and a fully replicated stockless rotational trial. Results from the trials are presented and the discussion recognises that stockless systems have appeared as agronomically and economically viable options for some organic farmers in the UK.

Throughout the paper lessons learnt and recommendations for future development of stockless systems are suggested in order that future long-term trials might benefit.

Introduction

With the growth of the organic sector throughout Europe it is inevitable that there will be an increasing number of conventional specialist arable farmers considering conversion to organic methods of production. Fragstein (1996) found that the proportion of stockless farms in Germany varied between 20 and 50%. Similarly, David *et al.* (1996) and Stopes *et al.* (1996b) reported that the stockless system is becoming increasingly important in organic farming systems in France and the U.K., respectively.

Rotations are the primary means of maintaining soil fertility and controlling weeds, pest and diseases in organic crop production systems (Lampkin, 1990). On a mixed organic farm, the grass-clover ley is expected to accumulate sufficient N by fixation to support subsequent arable crops. Grass-clover leys typically occupy at least 50% of the mixed farm area (National Rivers Authority, 1992), and the manure gener ated by the livestock can be used to stimulate biological activity and move nutri ents both around the farm and within the rotation.

Prior to the start of the EFRC stockless research programme in 1987 very little was known about the potential for stockless organic systems.

A stockless rotation will not include a long ley phase to provide a balance between fertility building and exploitative arable crops. The absence of a ley phase may also lead to greater problems with weeds, pests, diseases, soil structure, organic matter and fertility. Instead, short-term legu minous green manures may be used to accumulate N for the subsequent arable phases of the rotation. Trials on the duration, species composition and manage ment of leguminous green manures demonstrated that red clover, cut and mulched, can supply a considerable amount of N (Stopes *et al.*, 1996a).

Materials and methods

Three 4-year rotations were compared in three complete randomised blocks in an experiment at EFRC (Table 1). Every course of every rotation was present in each year, giving a total of 36 plots, each 20 × 12 m. The site was at an altitude of about 60 m with an average annual rainfall of 710 mm yr^{-1}. The soil is Wickham series, clay loam (Gleyic Luvisol) (FitzPatrick, 1980). The trial site was situated on a predominantly grass farm and not ideally suited for many arable crops.

Table 1 Rotations used in the replicated crop rotation trial (EFRC).

Course	Rotation A	Rotation B	Rotation C
1	Red clover	Red clover	Red clover
2	Winter wheat	Potatoes	Winter wheat
3	Winter wheat	Winter wheat	Winter beans
4	Spring oat	Winter oats	Winter wheat

Cultivations, sowing, planting, in-crop weed control and potato harvesting were carried out using standard farm equipment. The harvesting of the cereal crops and the field beans was carried out using a trial plot combine harvester. Throughout the experiment, rock phosphate was applied at a maximum rate of 180 kg ha^{-1} of P_2O_5 during the green manure phase of the rotations, at a rate chosen according to soil analysis and the requirement of the subsequent crops.

The following parameters have been assessed since 1987:

- green manure: dry matter (g m^{-2}) and N accumulation (kg ha^{-1});
- crops: yield; quality; nutrient off-take; establishment; weed dry matter (g m^{-2}); pests and diseases;
- soil: nutrient status, the soil data will be presented at a later date.

Results and discussion

These rotations were experimental and were designed to provide information about the robustness of stockless systems. The rotations were designed to test where the potential weaknesses lay within the system in terms of fertility, weed infestation or susceptibility to pest and disease problems. Rotation A was the most exploitative and least robust, rotation B, with the inclusion of potatoes was a high risk, high potential return option, and rotation C with an additional fertility component (winter beans) was a more moderate design. It was never intended that any of the three rotations would be recommended in their entirety by the organic advisory service as applicable in practice.

Green manures

Green manures were cut and mulched 3 to 5 times during the season, depending upon growing conditions. The average dry matter production was 11.0 t ha^{-1}, and the aboveground N accumulation was 240 kg ha^{-1}. Rotation B accumu lated the highest dry matter and nitrogen, although this was only significantly higher ($P<0.001$) than rotation C.

This work and that of Schmidt *et al.* (in press) confirms that nitrogen accumulation from green manure crops is capable of supporting three years of cash cropping, provided that the green manure crop establishes well. The establishment and performance of the green manure crops has not always been reliable and therefore, for stockless systems to be recognised it is important that undersowing and management of green manure crops is improved.

Since the establishment of this trial, the set-aside programme has been introduced with the objective of reducing food surpluses by taking land out of production (based on EU regulation No 1765/92). Set aside, promoted with subsidies and an agreement for organic farmers to use legumes on set aside land, has increased the possibilities for fertility building periods in stockless systems to be longer than one year.

Cash crops

There were no overall declines in cash crop yields over the eleven-year period, indeed some of the yields in the final, tenth, year were comparable with those in year 1. Climatic conditions, particularly at drilling, had a great influence on crop performance (Bulson *et al.,* 1996). The annual rainfall and yield data for the period of the trial are presented in Figure 1.

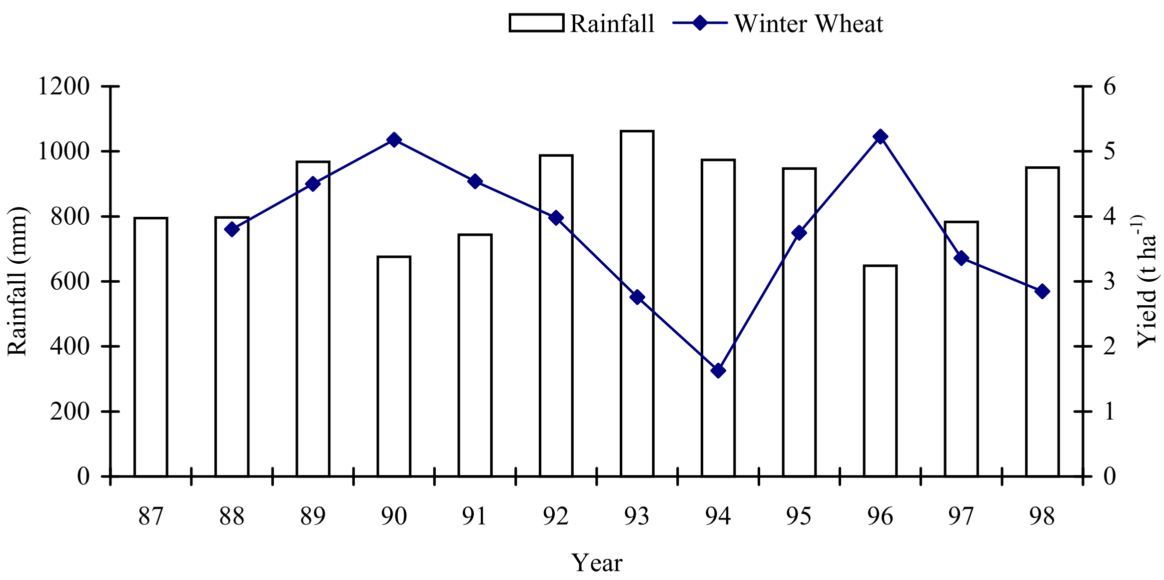

Figure 1 Annual Rainfall (mm) at Elm Farm Research Centre, 1987-1998 with corresponding winter wheat yields (t ha^{-1}).

Table 2 Average crop yield of cash crops from 1988 - 1998.

Course code	Crop	Previous crop	Mean yield (t ha^{-1})	s.e.	C.V. (%)
A2	Winter wheat	Red clover	4.29[1]	1.30	34
B2	Potatoes	Red clover	29.4[2]	8.81	30
			14.4[3]	3.60	25
C2	Winter wheat	Red clover	3.75[1]	1.30	34
A3	Winter wheat	Winter wheat	2.64[1]	1.30	34
B3	Winter wheat	Potatoes	4.29[1]	1.30	34
C3	Winter beans	Winter wheat	4.10[1]	1.09	27
A4	Spring oats	Winter wheat	2.03[1]	1.30	64
B4	Winter oats	Winter wheat	3.19[1]	0.99	31
C4	Winter wheat	Winter beans	3.99[1]	1.30	34

[1] Yields adjusted to standard 15% moisture content
[2] Total yield
[3] Ware (marketable) yield

Table 2 shows the average yields of all the cash crops. The first cereal crops following the red clover are typical of organic winter wheat yields reported by Lampkin and Measures (1999). The total potato yield was 29 t ha^{-1} with the marketable yield (14 t ha^{-1}) half the organic main crop average of 28t ha^{-1}. The cereal yield following the potato crop (B3) is only slightly below the organic average for winter wheat. The wheat yield following wheat was poor and as might be expected; this phase of the rotation frequently suffered severe weed competition. The performances of the winter beans were marginally below the organic average as reported by Lampkin and Measures (1999). The crops in the final phase of the rotations did less well than the organic average particularly the spring oats (A4). The spring oat yields were low and remained consistent over the eleven years. The yields of the winter oats and winter wheat in the last phase of the rotation were marginally below average.

Table 3 Nutrient off-takes from cash crops (N, P and K kg ha^{-1} yr^{-1}).

Rotation	*Course of rotation* Off-take per course 2	3	4	Mean per course	Total per rotation
Nitrogen					
A	55	17	19	30	91
B	87	53	30	57	170
C	50	-35	45	20	60
Phosphorus					
A	29	9	9	16	47
B	50	29	19	33	98
C	27	24	25	25	76
Potassium					
A	29	9	8	15	46
B	133	21	12	55	166
C	16	40	18	25	74

Table 3 presents the data for the quantity of N, P and K removed at harvest. Rotation B had the greatest off-take due to the inclusion of potatoes in the rotation and the generally higher yields. The off-take of nutrients were not considered to be limiting because the removal was being balanced by the return of crop residues, N fixation, breakdown of clay minerals to release K and the use of rock phosphate as necessary.

The original working methodology for the trial was very specific, but during the eleven years it became necessary to introduce more flexibility into the management protocol. Table 4 presents a summary of the major changes implemented during the lifetime of the project.

Table 4 Changes in the management of the EFRC stockless trial

Year	**Change**	**Reason**
1989	White clover ley at establishment of the trial was replaced by red clover as the green manure	Red clover was not established in the "inherited" ley plots in autumn 1987
	Spring sown mixed legume used instead of red clover	Red clover undersowing failed
	Winter oat variety changed from *Peniath* to *Solva*	*Solva* recommended variety
1990	Spring beans replaced by winter beans	Site difficult for timely spring sowings of spring beans
1992	Minimal cultivations between A2 and A3 winter wheats replaced by ploughing	To improve soil tilth, crop establishment and weed control
	Trefoil not undersown in A3 winter wheat as over winter green manure	Poor establishment of trefoil and to avoid additional cultivations to reduce soil compaction
	Potato variety *Cara* replaced with *Sante*	*Cara* late maturing earlier *Sante* allowed earlier harvest and reduced soil damage.
	Primary cultivations all carried out in autumn prior to spring crops. Previously cultivated in spring.	Spring cultivations tended to maximise over winter ground cover but often resulted in poor cultivations, which led to poor crop establishment.
1994	Compatible machinery with a 3m width used post ploughing on all plots	To limit soil damage over the plot area to "tramlines".
	Contractors employed to carry out field operations.	To ensure best machinery used and to control management costs
	"Accord" pneumatic drill used instead of the "Bettinson"	To prevent "wheelings" caused by the "Bettinson"
	"Einbock" tined weeder used on crops	To improve weed control.
1995	"Amazone RPD" power harrow drill combination used to replace "Accord"	To improve establishment by achieving good soil tilth, adequate sowing depth and reduced compaction
	Sowing date of cereals moved from mid/late October to early October	To improve establishment by sowing into a warmer seedbed
	Inter-row hoeing of A3 winter wheats, row spacings changed to 25 cm to accommodate hoe	To improve weed control.
1996	Reduced intensity of monitoring programme	Having collected 8 years of detailed data monitoring continued on a less intensive protocol to ensure further critical data was collected but without the resource constraints

Weeds

The weed biomass was monitored for the first eight years of the trial. There was no difference between the dry matter of weeds (g m^{-2}) in the first wheat A2 and C2. The spring oats A4 were significantly lower ($P<0.001$) in weed dry matter than the winter wheat C4.

The winter wheat in rotation B (B3) was significantly lower in weed dry matter at harvest than the wheat A3, as was the winter oats B4 compared with the winter wheat C4. The dry matter of weeds at harvest in all the winter wheat crops showed no significant relationship with time.

During the course of the project the weed control strategy developed to include inter-row hoeing as well as spring tine weeding. More attention was given to drilling the crops to ensure that a competitive crop was established. This was achieved by changing the row widths and the seed drill.

Disease and pests

The levels of disease and pests in all the crops was generally low, with no significant differences between the same crops grown in different rotations. The levels of disease and pests did not increase during the experiment and never reached levels that would be expected to restrict the performance of the crops.

During the lifetime of the trial there was a number of changes external to the research programme that influenced the direction of the project:

- The derogation for organic farmers to be able to use legumes in set aside to aid fertility building.
- Changes in recommended varieties
- Availability of some varieties.

The problems that the EFRC trial encountered were more to do with the problems associated with the limitations of the site and plot size rather than major failings of the stockless system.

With hindsight the scientific protocol may have been constructed in such a way to allow more flexibility. The trial may have been managed to 'best management practice' but should have been sufficiently flexible to allow changes for example, to ensure that the most modern varieties were used. In addition, each plot should have been managed as an individual management unit rather than trying to manage the whole site as a single unit; this approach would have been more in keeping with a whole system approach.

Other factors that may have influenced the trial but were not a direct effect of the system included changes of research and farm staff.

Conclusions

The overall results have demonstrated that stockless organic farming is a viable option in the U.K. The potential constraints of nutrient supply, maintenance of soil fertility and structure, weed, pest and disease control can all be satisfactorily achieved. The yields are comparable with those achieved by other viable organic farms and under current economic conditions organic stockless systems are economically viable.

This research programme has given confidence to organic advisers to implement stockless or predominantly arable rotations on an increasing number of organic farms in the U.K. In addition, the research programme has spawned a number of other research projects in this area.

The EFRC research programme has moved on to investigate the potential for improving the productivity of the organic system through developing cropping systems which attempt to even out nutrient supply and demand and increase biodiversity both spatially and temporally.

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Yield results during the first eight years crop rotation of the Apelsvoll cropping system experiment

R. Eltun and O. Nordheim

The Norwegian Crop Research Institute, Apelsvoll Research Centre, N-2858 Kapp, Norway

Summary

In the Apelsvoll cropping system experiment, the productivity, environmental side-effects and farm economy of the following six cropping systems are investigated: conventional arable (CON-A), integrated arable (INT-A), ecological arable (ECO-A), conventional forage (CON-F), integrated forage (INT-F) and ecological forage (ECO-F). Each system, all of which are eight-year crop rotations, is established on model farms of 0.2 ha each. Presented here are the yield results of the first crop rotation period. The average grain yields of barley in the systems INT-A, ECO-A, CON-F, INT-F and ECO-F were 85, 66, 95, 76 and 67%, respectively, of the CON-A system. Wheat grain yields showed an even greater yield reduction with ecological as compared to conventional cropping than barley, while a mixture of oats and peas gave higher yield than barley in ecological cropping. The grain protein content and grain size in ecologically grown wheat were lower than in conventionally grown wheat. Both for potatoes, root and forage crops, the yield reduction incurred by integrated and ecological cropping was smaller than for cereals, and it is concluded that, with regard to yields, a change from conventional to integrated or ecological cropping is easier to achieve in mixed farming systems with livestock than in arable farming systems without livestock. For cereals there tended to be a positive yield effect going from single (ARABLE) to mixed (FORAGE) cropping systems. Otherwise, the yield relations between individual crops and between cropping systems were fairly stable during this eight year cropping period, and it is postulated that, under most Norwegian conditions, the yields with integrated and ecological cropping will stabilise at a significantly lower level compared with the yields obtained with conventional farming.

Introduction

With the exception of on-farm case studies (Løes *et al.*, 1998a), there have previously been no investigations comparing different cropping systems in Norway. However, internationally there have been several such studies (e.g. Stanhill, 1990; Besson & Niggli, 1991; Halberg & Kristensen, 1997). We clearly need more knowledge about both the short and especially the long term effects of different cropping systems on for example yields and soil properties under Norwegian growing conditions.

A cropping system project with the aim of studying nutrient and pesticide leaching as well as soil fertility, yields, yield quality and economy of different cropping systems was established at Apelsvoll Research Centre in 1989. In the Apelsvoll cropping system experiment attention is paid to secure long term sustainability of the cropping systems and there is a focus on yields and soil nutrient conditions. The yields and yield quality results of the first four year cropping period (1990-93) were presented by

Eltun (1996a, b) and preliminary results on nutrient balances by Løes *et al.* (1998b) and Korsaeth & Eltun (1999). The objective of this paper is to evaluate the cropping systems with regard to yields and yield development during the first complete rotation period (1990-97).

Materials and methods

Experimental site and treatments

The experimental design, management of the individual cropping systems and soil conditions on the model farms were described by Eltun (1994) and Riley & Eltun (1994). Briefly, the experiment is being conducted at The Norwegian Crop Research Institute, Apelsvoll Research Centre, which is situated in central south-east Norway (60°42'N, 10°51'E, altitude 250 m).

The experiment is based on both traditional experimental methods and a systems approach, in which complete model farms are used as experimental units. Instead of using a fixed experimental layout, attention is paid to making improvements to the farming systems. The systems are adjusted every four years, depending on experience gained in the project and from other relevant sources. The experimental units include six types of farming system: conventional arable crop production (CON-A), integrated arable crop production (INT-A), ecological (organic) arable crop production (ECO-A), conventional forage crop production (CON-F), integrated forage crop production (INT-F) and ecological (organic) forage crop production (ECO-F).

The main differences between the cropping systems for the period 1990-97 are presented in Table 1. Notice that the ECO-A system, in contrast to the two other arable systems, has grass-clover in the crop rotation, which for some parameters limits the possibility for comparisons among the arable systems and also between the arable and forage systems. Notice also the changes made in 1994 with regard to crop rotation, amounts of fertiliser, the time of fertiliser application and the time of ploughing, which are likely to have affected the yield results. There was also some variation in varieties between the cropping systems (Eltun, 1994), however, except for potatoes where the variety in the ECO-A system was changed from *Danva* to *Troll* in 1994, the same varieties were grown in all years. Thus, the variety differences are not thought to affect the proportional yield differences between the cropping systems.

Each cropping system is represented on two model farms of 0.18 ha. Each model farm has eight rotation plots and an eight-year crop rotation. All the crops in each rotation are thus present each year. The field design is a split-plot experiment with the factor cropping method (ARABLE, FORAGE) on major plots and cropping intensity (CON, INT, ECO) on subplots. The measurements of the yields, yield quality and the statistical methods used were described by Eltun (1996a, b).

Growing conditions

The climate of the region is humid continental with a mean annual precipitation of 600 mm (1961-90) and a mean annual temperature of 3.6°C. In the growing period May-September the normal temperature is 12.1°C. The average date for the commencement of spring work is May 4. The major soil groups in the experiment are well or imperfectly drained brown soils, and the dominant soil textures are loam and silty sand, with a humus content of about 6% in the topsoil. It is considered to be a fertile soil.

As shown in Figure 1, the summers of 1990-92 were fairly warm, and the first two years were especially dry. This weather pattern changed in 1993, as that year had a cool and wet summer. In 1994 there was a peak on the precipitation curve in June, followed by a short period with very warm, dry weather, and later on more normal temperature and precipitation conditions. The early summer was wet also in 1995, while there was drought in the late summer and autumn of that year. Both temperature and precipitation were close to normal during the growing season of 1996. In the final year (1997) there were good growing conditions early in the summer, while July and August were unusually warm and dry.

Table 1 Crop rotations and cultivation methods of the cropping systems. Changes in the systems from the 1994 growing season onward are shown in parentheses

Crop rotation	Mineral fertiliser Kg N ha^{-1}	Slurry [a] Mg ha^{-1}	Soil Tillage	Crop rotation	Mineral fertiliser kg N ha^{-1}	Slurry Mg ha^{-1}	Soil tillage
Conventional arable (CON-A)				Conventional forage (CON-F)			
Early potato[b]	120 (110)	0	Autumn plough (Spring plough)	Barley	80	40 (20)	Autumn plough (Spring plough)
Winter wheat	130 (140)	0		1st year ley	160 (140)	20	
Oats	110	0		2nd year ley	120 (140)	40 (30)	
Barley	120 (110)	0		3rd year ley	120 (140)	40 (30)	
Late potato	110	0		Fodder-beet[c]	130 (80)	100 (60)	
Spring wheat	130	0		Spring wheat	90	20	
Oats	110	0		Oats	70 (100)	20	
Barley	120 (110)	0		Green fodder	100 (70)	80 (60)	
Integrated arable (INT-A)				Integrated forage (INT-F)			
Early potato[b]	70	0	Spring harrow	Barley	0 (40)	30 (20)	Spring plough
Winter wheat	80 (90)	0		1st year ley	110 (90)	10	
Oats	60 (70)	0		2nd year ley	70 (80)	30 (20)	
Barley	70	0		3rd year ley	70 (80)	30 (20)	
Late potato	60 (70)	0		Fodder-beet[c]	50 (0)	50 (60)	
Spring wheat	80	0		Spring wheat	40 (50)	20	
Oats	60 (70)	0		Oats	30 (50)	20	
Barley	70	0		Green fodder	30 (30)	50	
Ecological arable (ECO-A)				Ecological forage (ECO-F)			
Barley	0	10	Spring plough	Barley	0	20 (30)	Spring plough
Clover grass ley	0	0		1st year ley	0	20	
Spring wheat	0	20 (10)		2nd year ley	0	20	
Late potato	0	10 (20)		3rd year ley	0	20	
Barley	0	20 (10)		Fodder-beet[c]	0	40	
Clover grass ley	0	0		Green fodder	0	20 (10)	
Winter wheat	0	10		Spring wheat	0	20 (30)	
Oats	0	0 (10)		Oats and peas	0	20	

[a] In the first four years all slurry was spread in the spring and after first grass cutting in the integrated and ecological cropping systems, while in the conventional systems about 35 % of the slurry was spread in the autumn. From 1994 onward, all the slurry was spread in the spring or during the growing season in all cropping systems

[b] Barley in the period 1994-97

[c] Swede in the period 1994-97

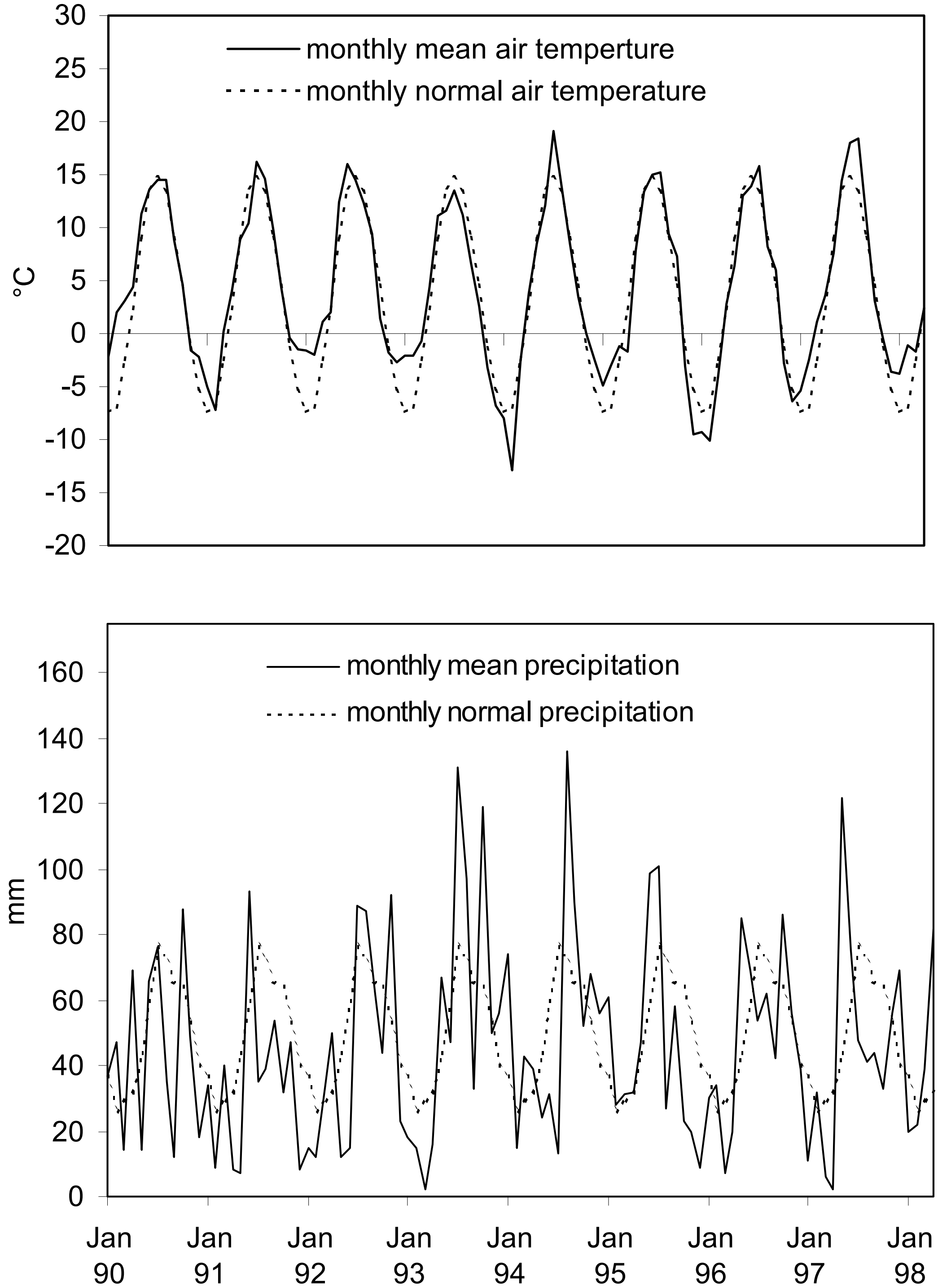


Figure 1 Monthly mean air temperature 2 m above ground and monthly precipitation in the years 1990-97, compared with normal monthly temperature and precipitation for the period 1961-90 at Apelsvoll.

The winter 1990/91 was fairly dry, but with normal temperature conditions. The two following winters were unusually mild, and there were several occasions with snowmelt and surface runoff during the winter. The winter 1993/94 was cold with plenty of snow. The next winter (1994/95) was somewhat milder than normal, while the winter 1995/96 was exceptionally dry and cold, resulting in very deep ground frost and late spring work (Table 2). The final winter (1996/97) was fairly typical with regard to both temperature and precipitation, but the frost stayed in the soil until the middle of May, and the spring work was delayed as a result.

As shown in Table 2, sowing and planting was early in the first five years. The ripening and harvesting of the cereals was on normal dates in the first three years. In 1993 it was delayed due to cool and wet weather, while in 1994 it was brought forward because of drought. In the last three years spring work was late, but harvesting was completed at normal dates.

Table 2 Dates of sowing, planting and harvesting in the years 1990-97.

Task	1990	1991	1992	1993	1994	1995	1996	1997
First day of sowing	27 Apr	2 May	10 May	30 Apr	6 May	21 May	23 May	20 May
Potato planting	9 May	7 May	18 May	18 May	16 May	26 May	28 May	3 Jun
Root crop planting	28 May	27 May	25 May	25 May	24 May	12 Jun	4 Jun	5 Jun
First ley cut	11 Jun	27 June	15 Jun	15 Jun	21 Jun	26 Jun	27 Jun	19 Jun
Second ley cut	7 Aug	12 Aug.	7 Sep	25 Aug	24 Aug	22 Aug	28 Aug	20 Aug
First day of threshing	21 Aug	26 Aug	19 Aug	2 Sep	10 Aug	24 Aug	22 Aug	18 Aug
Last day of threshing	9 Sep	4 Sep	2 Sep	13 Oct	16 Aug	15 Sep	17 Sep	9 Sep
Lifting of potatoes	12 Sep	12 Sep	10 Sep	16 Sep	23 Sep	20 Sep	19 Sep	23 Sep
Harvest of root crop	23 Sep.	16 Sep	28 Sep	27 Sep	19 Sep	4 Oct	24 Sep	6 Oct

In summary, growing conditions were good in the years 1990-92, while low temperature and high rainfall (1993), heavy rain, soil structure damage and drought (1994), drought (1995), ground frost and late spring work (1996 and 1997) resulted in somewhat poorer growing conditions in the later years. As a whole, the period 1990-97 gave a good representation of the normal variation in growing conditions, which are encountered in the region.

Results and discussion

Average yields of the cropping systems

There was, on average for the first eight years, and with the exception of the two ecological systems, a tendency towards higher cereal yields in the arable systems than in the forage systems (Table 3), but this difference was not statistically significant. Wheat gave the highest yield with both conventional and integrated cropping, while oats and the oats and peas mixture were the highest yielding cereals in the ecological cropping systems. The yields of barley in the systems INT-A, ECO-A, CON-F, INT-F and ECO-F were 85, 66, 95, 76 and 67%, respectively, of the CON-A system. The oats and peas mixture in the ECO-F system had a yield reduction of only 17% as compared with oats in the CON-A system. In the other systems oats gave about the same yield reduction as barley compared to the CON-A system. Wheat performed poorest in the ecological systems with a yield reduction, as compared with the CON-A system, of 40% for the ECO-A system and 37% for the ECO-F system. The integrated grown wheat gave 16% lower yield than conventionally grown wheat. Based on these results and other Norwegian investigations (Kerner, 1994), it appears that the yield level in ecological cereal cropping, as compared with conventional cropping, tends to be lower in Norway than in countries further south (Besson *et al.*, 1992; Holm, 1991; Nilsson *et al.*, 1991; Stanhill, 1990). The most likely reasons for this seem to be low temperature and limitations in nutrient mineralisation and nutrient availability during the early growth stages. Differences in disease attack appear to be of minor importance (Eltun, 1996a).

Ecological growing resulted in lower grain weight for all cereal crops than did conventional and integrated growing. The protein content and starch quality (falling number) in wheat were reduced by both integrated and ecological cropping as compared with conventional cropping. With the exception of falling number in the ECO-A system, the reduction was greatest in the ecological cropping systems.

The fresh weight of integrated and ecologically grown potatoes was 13 and 25% lower, respectively, than that of conventionally grown potatoes (Table 3). However, the dry matter content of the integrated and ecologically grown potatoes was higher than that of the conventionally grown potatoes, and there was thus no significant difference between the cropping systems in total dry matter yield. In many cases, the most important limiting factor for good potato yields in ecological cropping is late blight (*Phytophthora infestans*) (Mølgaard, 1999). In this experiment, however, late blight only caused minor damage with ecological cropping, and the yield differences between the cropping systems appeared to be associated with the nutrient supply. Measurements of mineral nitrogen in the soil at the end of the growing season showed lower values in the ecologically than in the conventionally grown potatoes (Eltun & Fugleberg, 1996). Due to lower incidence of problems with late blight than in countries with warmer and more humid climate it seems that the conditions for ecological potato production is good in Norway (Besson *et al.*, 1991; Kerner, 1994; Mølgaard, 1999).

In grass leys there was a tendency towards reduction in yield with increasing ley age, but this was not statistically significant (Table 3). On average for all three ley years, the yields of the INT-F and the ECO-F system were 95 and 75%, respectively, of the CON-F system. The yield reduction in ecological farming was about 10% greater in this experiment than in Norwegian on-farm studies of conventional and ecological farms (Ebbesvik, 1997). The reason is difficult to explain, but it may be due to variation in measurement years, soil and climatic onditions. The herbage dry matter concentration increased in the order ECO-F< CON-F< INT-F, while the clover percentage increased in the order CON-F< INT-F< ECO-F. The dry matter concentration is affected by both nitrogen fertilization and clover content (the dry matter content of clover is normally lower than that of grass). In this case the level of fertilisation and clover content attained in the INT-F system gave the highest dry matter concentration.

The green fodder yield was highest in the conventional system, while there was no significant yield difference between the integrated and the ecological system (Table 3). Swede yields were equally high for all systems suggesting that this crop is very efficient in utilisation of nutrients from manure and organic sources in the soil, probably due to its active growth late in the season.

Table 3 Average yields and yield quality characteristics of spring cereals, late potatoes and forage crops in the first crop rotation period 1990-97.

	Cropping system						LSD
Measured variable	**CON-A**	**INT-A**	**ECO-A**	**CON-F**	**INT-F**	**ECO-F**	**5%**
Barley, 15 % water, Mg ha^{-1}	5.9	5.0	3.9	5.6	4.5	3.9	0.3
Oats [a], 15 % water, Mg ha^{-1}	6.0	5.2	4.1	5.8	4.7	5.0	0.3
Wheat, 15 % water, Mg ha^{-1}	6.4	5.3	3.8	6.2	5.4	4.0	0.3
Potato [b], fresh weight, Mg ha^{-1}	35.8	32.5	29.2	-	-	-	5.4
Potato, DM, Mg ha^{-1}	8.1	7.5	6.9	-	-	-	n.s.
1st year ley, DM, Mg ha^{-1}	-	-	-	10.7	10.3	8.4	0.6
2nd year ley, DM, Mg ha^{-1}	-	-	-	11.0	10.3	8.4	0.6
3rd year ley, DM, Mg ha^{-1}	-	-	-	10.4	9.8	8.2	0.6
Green fodder, DM, Mg ha^{-1}	-	-	-	7.6	6.8	7.1	0.4
Swede[b], roots, DM, Mg ha^{-1}				9.0	8.6	9.3	n.s.
Entire crop. sys., DM, Mg ha^{-1}	5.5	4.8	(4.9)[c]	8.7	8.0	7.1	0.2/0.3 [c]
Barley, 1000 grain wt., g	47.8	47.0	45.4	49.1	49.0	44.9	1.2
Oats, 1000 grain wt., g	30.4	31.4	31.0	30.0	31.6	30.0	0.9
Wheat, 1000 grain wt., g	35.4	36.5	32.0	35.2	37.0	33.7	0.9
Wheat, protein content., %	12.8	12.0	10.8	13.2	11.5	10.1	0.3
Wheat, falling number	315	278	294	280	266	238	30
Potatoes, DM %	22.5	23.1	24.1	-	-	-	0.6
2nd year ley, 1st cut, DM%	-	-	-	22.5	23.3	21.7	n.s.
2nd year ley, 2nd cut, DM%	-	-	-	26.9	28.6	24.6	1.8
2nd year ley, 1st cut, clover %	-	-	-	9	12	20	6.0
2nd year ley, 2nd cut, clover %	-	-	-	12	18	39	6.0

[a] Mixture of oats and peas in system ECO-F
[b] The results of potatoes and swede are for 1994-97 and those of ley are for 1993-97
[c] Because of different crops in the systems, only systems with the same crops are compared: CON-A and INT-A and CON-F, INT-F and ECO-F

The overall dry matter yield of all crops in the INT-A system was 87% of the CON-A system, while the INT-F and ECO-F systems yielded 92 and 82%, respectively, of the CON-F system (Table 3). The proportional yield differences between the cropping systems presented here for the complete eight year crop rotation were almost the same as those for the first four year cropping period, which were presented and discussed by Eltun (1996a, b). The magnitude of the differences between conventional and ecological cropping corresponds very well with those found in recent Danish investigations (Halberg & Kristensen, 1997). On the basis of these results, it is concluded that the yield reduction incurred by integrated and ecological cropping is smaller for forages, root crops and potatoes than it is for cereals. This suggests that, with regard to yield level, a change from conventional to integrated or ecological cropping is easier to achieve in mixed farming systems with livestock than in arable farming systems without livestock. This is in agreement with the present trend in Norwegian agriculture.

Yield development of the cropping systems

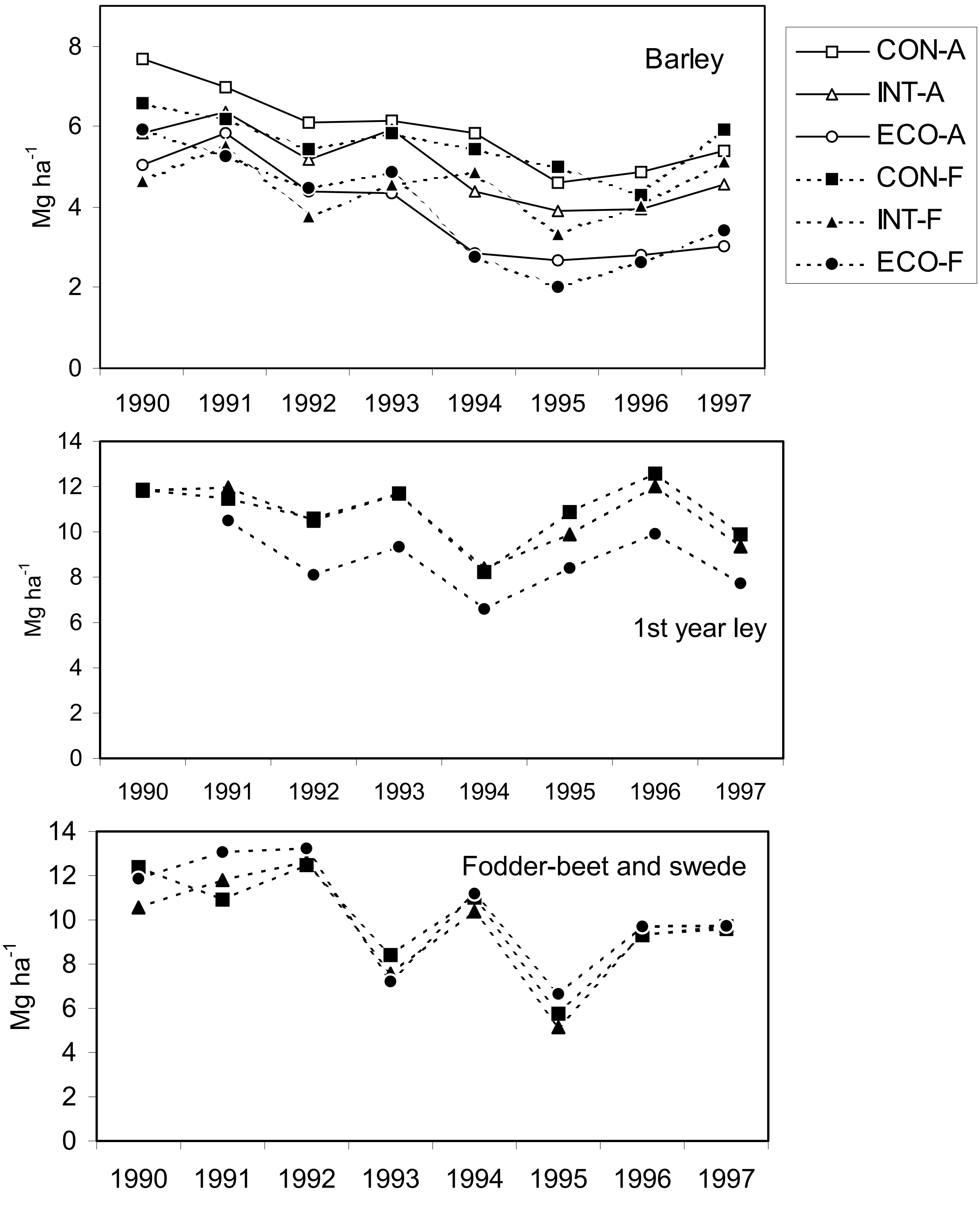
Figure 2 shows examples of yield variations for crops in the various systems. In general, the variation was greatest for cereals, fodder crops and potatoes and smallest for leys. The main reasons for the variation are associated with variations in growing conditions, such as precipitation, temperature, commencement of spring work or with special soil conditions in the different growing seasons, such as compaction and surface crusting. Better growing conditions during the first years than in later ones appears to be the main reason for a general decrease in the yield level over the eight years. A yield level in 1998 (not shown here) comparable with that obtained in the first years supports this theory.

Barley and wheat (wheat not shown here) gave lower yields in the forage systems than in the arable systems during the first years. In the later years, however, the yields were equally high in all systems. For integrated grown barley the change can be explained by the increase in fertiliser application from 1994 (Table 1), whereas for the other systems there have only been minor differences in fertiliser level during these years. Thus, it appears that there has been a "conversion effect" where the value of mixed cropping (forage systems) has shown up at the end of the rotation period.

Figures 2 and 3 also demonstrate that the yield relations, with the exceptions mentioned above, between individual crops and for entire cropping systems were fairly stable during this eight year cropping period. An initial yield depression, followed by a fairly stable yield level after conversion to ecological farming, is in good accordance with on-farm investigations on mixed farms in Norway (Ebbesvik, 1997). Källander (1989) presented a curve showing an increasing yield level following a decline after the start of the conversion. The reason for the increase is thought to be an increase in soil organic matter and plant available nitrogen after some years of ecological farming. It appears that both the course of the yield curve and the long-term yield level after conversion depend on the climate, the type of crop rotation before and after conversion, the soil type, the content of organic matter in the soil and the weed status. In cases where the soils are in good nutrient and organic matter status, as is very often the case in Norway, the chance of increased organic matter content leading to enhanced yields is limited. Thus, we conclude that even if it may takes a long time for the yield level to stabilise after conversion to ecological farming (Besson *et al.*, 1991), the yields in ecological farming, under most Norwegian conditions, will stabilise at a significantly lower level than the yields obtained formerly with conventional farming.

Acknowledgements

This work was financed by Norsk Hydro AS and the Norwegian Ministries of Agriculture and Environmental Protection, and we express our thanks for their support. We also want to thank Dr. Hugh Riley for giving valuable comments on on the manuscript.



Barley
1st year ley
Fodder-beet and swede
Mg ha-1
CON-A
INT-A
ECO-A
CON-F
INT-F
ECO-F
1990
1991
1992
1993
1994
1995
1996
1997

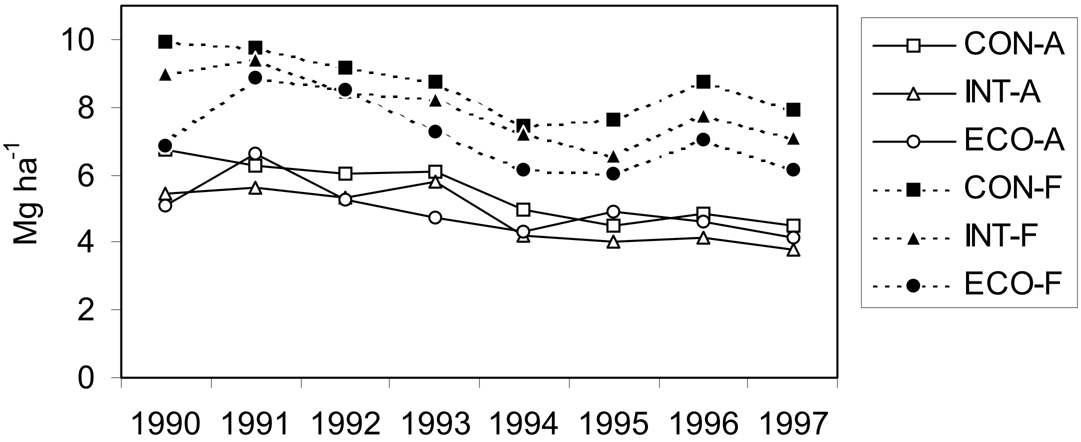


Figure 3 Average dry matter yields of all crops in the entire cropping systems during the years 1990-97.

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Designing crop rotations for organic farming: importance of the ley/arable balance

C.A. Watson, D. Younie and G. Armstrong
SAC, Craibstone Estate, Aberdeen AB21 9YA, UK

Summary

The design of crop rotations is fundamental to the success of organic farming systems. In particular, the ratio of nitrogen fixing crops to exploitative arable crops will have a major impact on agronomic success and the environment. This paper describes some of the results from a series of rotational trials, established in 1991 at two sites of contrasting soil fertility in northern Scotland (Tulloch and Woodside). The trials were designed to explore the relationships between ley/arable balance, productivity and environmental impact of organically managed rotations. Grain yields were higher in the first cereal following ley (5.42 and 4.85 t ha^{-1} following a 3 year ley at Tulloch and Woodside respectively) than in subsequent cereal crops (4.32 and 3.81 t ha^{-1} at Tulloch and Woodside respectively). Earthworm populations were greatest following multiple years of grass-clover ley. Further information on the overall relationship between the ley/arable balance and rotational productivity is currently being analysed.

Introduction

Crop rotations based on the use of perennial legumes offer an important mechanism for nitrogen management in farming systems, because they have the potential to support both animal production during the ley phase and a subsequent, exploitative, cropping phase. In organic farming systems, which rely on nitrogen fixation as the major external source of nitrogen, the balance between length of ley and length of arable period is critical in determining both crop production and environmental impact. Differences in organic matter management practices associated with different rotations, have recently been shown to impact on the retention of soil carbon and nitrogen, which has associated environmental benefits (Drinkwater *et al.*, 1998). However, it is also recognised that despite the positive effects of grass-clover leys on arable production, relying on grass-clover leys does impose restrictions on farming systems in terms of the mix of enterprises (Younie *et al.*, 1995). There is currently a lack of information available on optimising the ley/arable balance in organically managed systems (Johnston *et al.*, 1994).

This paper describes a long-term experiment comparing different crop rotations at two sites in northern Scotland.

Materials and methods

Replicated rotational trials comparing rotations with different ratios of ley to arable (38:62, 50:50 and 67:33) were established at Tulloch Organic Farm, Aberdeen (02°15'W, 57°11'N) and Woodside Organic Farm, Morayshire (03°24'W, 57°38'N) in 1991. Each rotation is replicated twice at each site, the plots are 0.08 ha at Tulloch and 0.09 ha at Woodside. Table 1 gives details of the soil characteristics and rainfall at each site. The plots are large enough to allow a core group of grazing animals, thus allowing natural recycling of nutrients to pasture. The trial design is such that all courses of the rotation are present every year. Further details of the trials can be found in Watson and Younie (1995). The rotations are described in Table 2.

Table 1 Site characteristics.

	Tulloch	Woodside
Soil Texture	**Sandy loam**	**Loamy sand**
OM %	8.8	5.9
Extractable P (mg l^{-1})	20.7	6.7
Extractable K (mg l^{-1})	95.3	67.4
Annual rainfall (mm)	820	730

Table 2 Rotational design.

	Rotation 1 (Woodside only)	Rotation 2 (Both sites)	Rotation 3 (Tulloch only)
Percentage ley**	38	50	67
1	Grass/white clover	Grass/white clover	Grass/white clover
2	Grass/white clover	Grass/white clover	Grass/white clover
3	Spring cereal (C1)	Grass/white clover	Grass/white clover
4	Potatoes	Spring cereal (C1)	Grass/white clover
5	Spring cereal (C2)*	Potatoes/swedes	Spring cereal (C1)
6	Grass/red clover	Spring cereal (C2)*	Spring cereal (C2)*
7	Swedes		
8	Spring cereal (C3)*		

* Undersown with grass/clover.
** All leys are managed by a combination of cutting and grazing.

Results and discussion

Grain yields and nitrogen offtake

One of the major difficulties associated with carrying out research on crop rotations is the relatively long establishment time before rotations can be assessed in terms of their true effects on production and nutrient cycling. Within the first four years of this trial, crop sequence was shown to have little effect on soil microbial biomass (Watson *et al.*, 1996). Figure 1 shows the relationship between the age of the experiment and nitrogen offtake in grain at Tulloch. This trend is also reflected at the Woodside site. Throughout the life of the experiment so far, there has been a gradual increase in nitrogen offtake, suggesting that there may be a developing effect of crop choice and sequence on soil quality. These results may reflect the observation that when farmers convert from conventional to organic management there is frequently a period of suppressed yields (Liebhardt *et al.*, 1989).

Nitrogen offtake (Figure 1) and grain yield (Tables 3 to 5) have been consistently higher in the first cereal following a ley than in subsequent cereal crops. Grain yields have only been presented for the 1995 growing season onwards, allowing the results to be viewed as residual effects of the previous four years cropping on each plot. Rotation 2 (50% grass-clover ley) which is replicated at both sites, illustrates the lower output per ha at Woodside. This is not unexpected given the relatively lower soil fertility, rainfall and water holding capacity of the soil at this site. The highest mean yield of any cereal (5.82 t ha^{-1}) occurred in rotation 3 at Tulloch, that is, after the longest ley period in the trial (4 years). However, the overall relationship between ley/arable balance and yield is unclear and a full statistical analysis of the data is needed before any conclusions can be drawn.

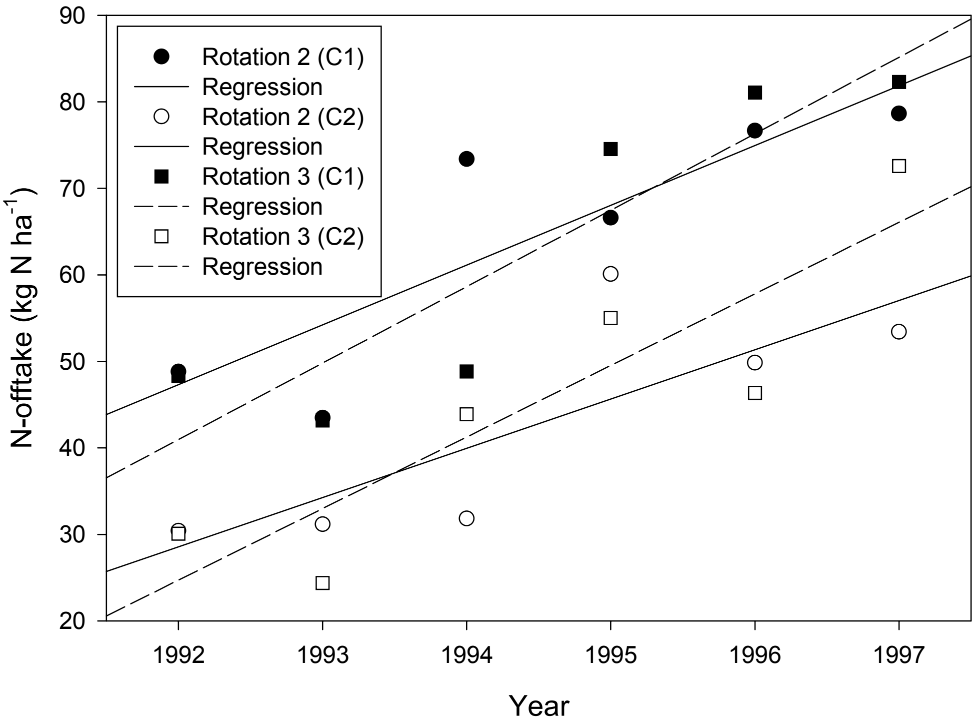


Figure 1 N-offtake in grain in cereal crops C1 and C2 in the two rotations at Tulloch (1992-97).

Table 3 Grain yields at different stages in rotation for rotation 1 with 38% ley (t ha^{-1} at 15% moisture, mean of 2 replicates).

Site	**Woodside**	**Woodside**	**Woodside**
Cereal	C1	C2	C3
Position in rotation	3	5	7
1995	2.82	2.21	2.27
1996	6.14	6.16	5.80
1997	5.34	4.52	3.56
Mean	4.77	4.30	3.88
Standard deviation	1.56	2.10	1.75

Table 4 Grain yields at different stages in rotation for rotation 2 with 50% ley (t ha^{-1} at 15% moisture, mean of 2 replicates).

Site	**Woodside**	**Woodside**	**Tulloch**	**Tulloch**
Cereal	C1	C2	C1	C2
Position in rotation	4	6	4	6
1995	2.82	2.40	5.56	4.85
1996	5.81	5.97	5.17	3.77
1997	5.92	3.07	5.53	4.34
Mean	4.85	3.81	5.42	4.32
Standard deviation	1.63	1.78	0.40	0.66

Table 5 Grain yields at different stages in rotation for rotation 3 with 67% ley (t ha-1 at 15% moisture, mean of 2 replicates).

Site	**Tulloch**	**Tulloch**
Cereal	C1	C2
Position in rotation	5	6
1995	6.11	4.44
1996	5.55	3.24
1997	5.77	4.82
Mean	5.82	4.17
Standard deviation	0.47	0.86

Potassium dynamics

Although a high proportion of grass-clover in the rotation will make a significant positive contribution to the N status of the soil, conserved grass removes substantial quantities of K, and frequent cutting for hay or silage may lead to significant reductions in exchangeable K content in the soil, even within one season (Figure 2). At the sandy loam site (Tulloch), the relationship between first cut yield and soil K content in the following winter was significant at the $P<0.001$ level. The relationship was not significant at the loamy sand site (Woodside), where other factors, such as soil moisture availability, may have been restricting yield.

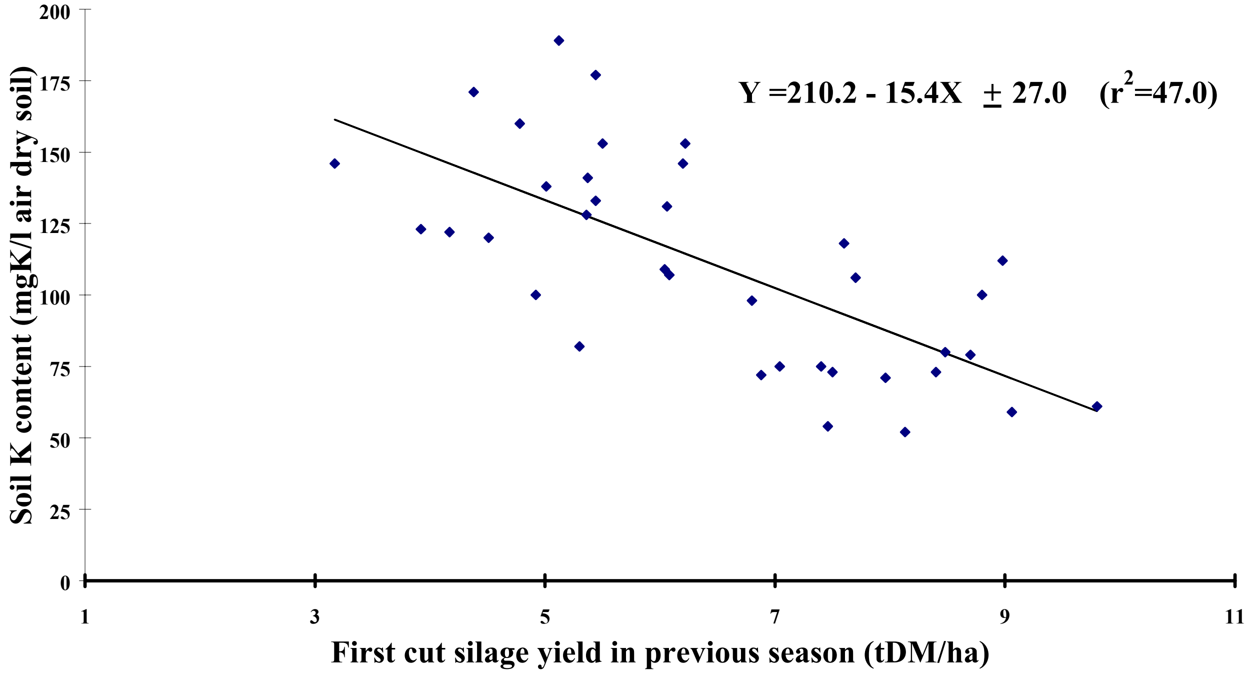
Earthworm populations
Many studies have shown that organic farming practices such as the inclusion of grass-clover leys have a beneficial effect on earthworm populations (e.g. Scullion and Ramshaw, 1987). Figure 3 illustrates the build-up of earthworm populations following ley establishment and the beneficial effect of multiple years of grass/clover ley for earthworm populations. This effect of ley length on earthworm populations has also been observed by Neale and Scullion (1998).

Future work
This paper illustrates some of the results from the ongoing rotational trials at SAC. Additionally, we are recording animal production and measuring soluble inorganic and organic nitrogen, P, K and Mg in soil at regular intervals. Measurements of gaseous nitrogen losses are also ongoing. We are in the process of carrying out a full statistical analysis of data for the period 1991-1998, which will allow conclusions to be drawn about the relationship between the ratio of ley and arable crops and the agronomic and environmental success of these rotations.

Acknowledgements

SAC acknowledges financial support from the Scottish Office Agriculture, Environment and Fisheries Department.

(a) Sandy loam (Tulloch)



b) Loamy sand (Woodside)

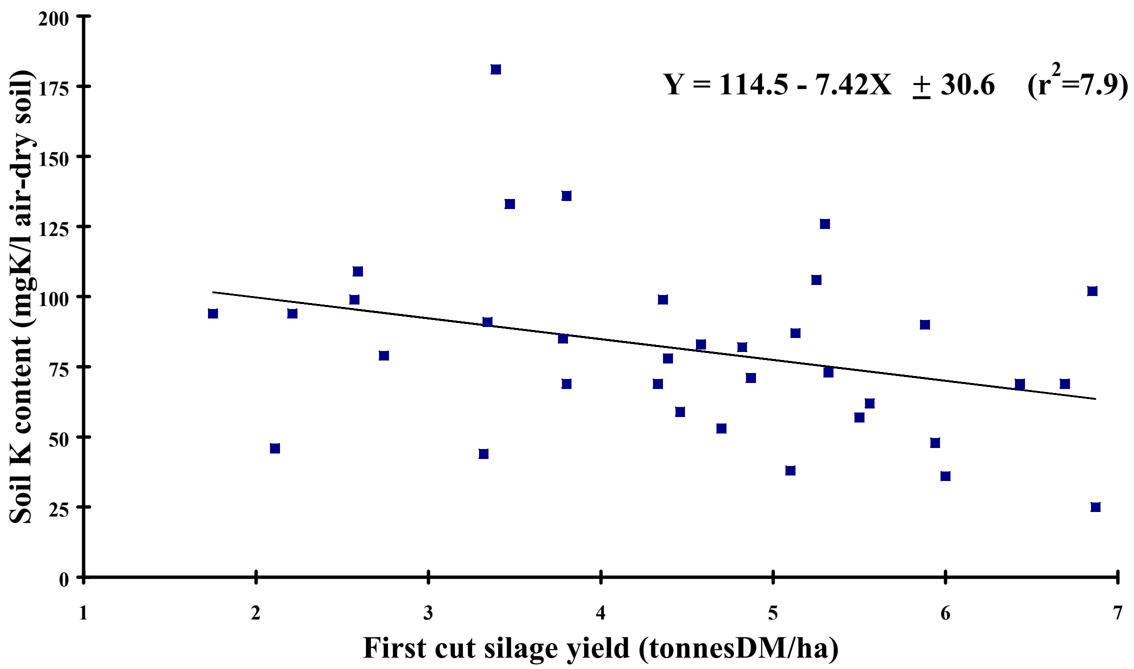


Figure 2 Effect of first cut silage yield in previous season on soil K content at Tulloch (a) and Woodside (b).

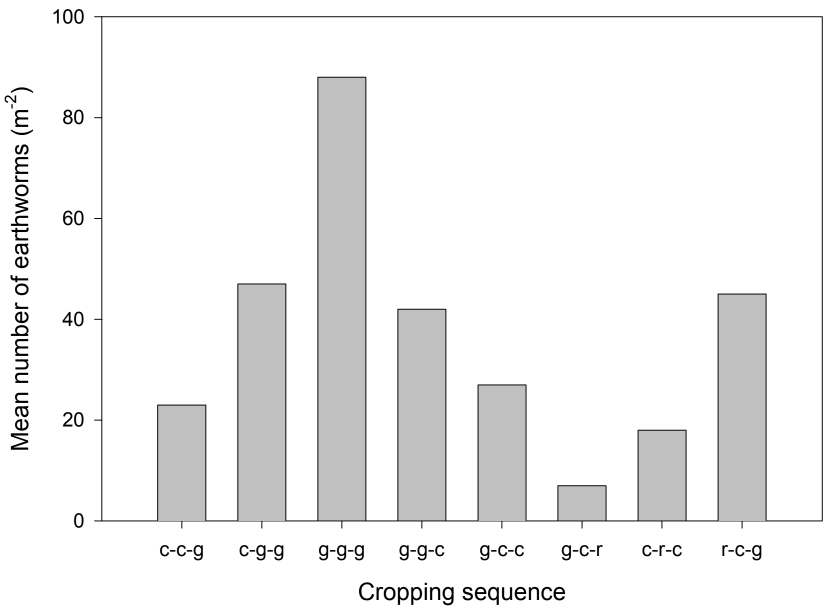


Figure 3 Effect of cropping sequence (grass, cereals, roots) on numbers *Lumbricus terrestris*.

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Crop rotation research in Central Oltenia

G. Paunescu and F. Ionescu
Agricultural Research Station Craiova, Soseaua Balcesti 14, Simnic-Craiova, Romania

Summary

An experiment with different crop rotations including wheat and maize has been conducted over 36 years in Romania at the Agricultural Research Station Simnic-Craiova on a brown-reddish slightly luvic soil. Both continuous wheat or maize and the crop rotation "wheat-maize" reduced crop yields relative to a four-year crop rotation including pea or oat. The yield decrease of the continuous cropping and the simple wheat-maize rotation was mainly induced by increasing incidence of weeds and diseases. The four-year crop rotation gave high and stable yields, especially when including a legume crop in the rotation.

Introduction

When research was planned 40 years ago at the Agricultural Research Station Simnic-Craiova, crop rotations played an important role in farming, and opinions as to the function of these were quite diverse. Some agronomists argued that crop rotations represent a theory completely overcome by the technological progress including the use of agrochemicals. This argument was based on the observation that continuous cropping was normal practice in some regions with favourable conditions for some crops, e.g. wheat in Canada and maize in the Corn Belt, USA (Braun, 1965). Other specialists supported the idea that the soil fertility depends on biological factors favoured by relatively long rotations.

Long-term rotation experiments have been conducted in several countries (Braun, 1965; Cox & Sloppe, 1965; Bogulawski, 1969; Koch, 1970) leading often to the conclusion that the rotation effect only occurs after many years of cropping, and that the rotation has multiple effects on the attained yield levels. Short-term experiments conducted in Romania have shown that legumes are very good preceding crops and that the rotations generally contribute to a yield increase of 12% as an average over the country (Inonescu-Sisesti & Staicu, 1958; Sinca & Tabaranu, 1966; Simota & Cornea, 1968; Pintilie & Sin, 1974; Ionescu & Paunescu, 1988).

This paper describes a long-term crop rotation experiment carried out in Romania with the comparison of wheat and maize in different rotations with continuous cultivation of these crops.

Materials and methods

The crop rotation experiment has been conducted at the Agricultural Research Station Simnic Craiova since 1954, for 36 years in total (1955-1994) giving nine four-year cycles of the rotations. The crop rotations tested included continuous cropping of wheat and maize, a two-year wheat-maize rotation, and four-year rotations that also included a legume crop (Table 1). The rotations were tested in two to four different fertiliser regimes; no fertiliser, 50 kg N/ha + 30 kg P ha^{-1}, 100 kg N ha^{-1} + 60 kg P ha^{-1}, or 40 t ha^{-1} manure every four years. All plots in the rotations were represented every year. Each plot had a size of 100-150 m^2. The treatments fertiliser × crop rotation were completely randomised within each of five blocks (replications).

The soil type at the experimental site was a brown reddish weakly luvique soil having a humus content of 2%, total nitrogen content of 0.11-0.12%, mobile potassium of 87-116 ppm and mobile phosphorus of 10-13 ppm.

Weeds were controlled in the experiment by mechanical methods.

The measurements included determination of grain yield every year. The weed seedbank in the upper 30 cm of the soil was determined five times during the 36 year experimental period by seed germination of sampled soil. Attack of Fusarium on wheat spikes and maize stems was determined every year at physiological maturity.

Results and discussion

During the experimental period 1959-1984 crop yields of wheat and maize were grouped into 9 cycles of four years each (Figures 1 to 3). Table 1 shows that there were positive effects of crop rotations for both wheat and maize compared with continuous cropping. The highest yield on average of the 36 years was obtained with the four-year rotation that included a legume crop (peas). It is followed by the four-year rotation with oat. The wheat-maize rotation had only a very small effect on wheat yields compared with continuous wheat. Maize was better able to support itself under continuous cropping and in the simple wheat-maize rotation. The yield increase from the four-year rotations was therefore smaller for maize compared with wheat. This was especially the case in the unfertilised plots. It should be noted from Table 1 that the use of fertilisers or manure did not reduce the rotation effect, but actually in some cases increased this effect.

Table 1 Average grain yields (t ha^{-1}) of wheat and maize in the different rotations and fertilisation regimes.

	Fertiliser regime			
Rotation	**None**	**$N_{50}P_{50}$**	**$N_{100}P_{60}$**	**Manure**
Wheat				
Continuous wheat	1.7	2.6	3.0	2.4
Wheat-maize	1.9	3.0	3,3	2.7
Pea-wheat-maize-maize	3.1	4.6	4.5	
Oat-wheat-maize-maize	2.3	3.5	4.0	
LSD 0.95	0.2	0.3	0.3	0.2
Maize				
Continuous maize	2.9	3.6	3.7	3.6
Wheat-maize	3.0	3.8	4.1	3.8
Pea/oat-wheat-**maize**-maize	3.6	4.6	4.8	
Pea/oat-wheat-maize-**maize**	3.4	4.3	4.4	
LSD 0.95	0.3	0.3	0.3	0.3

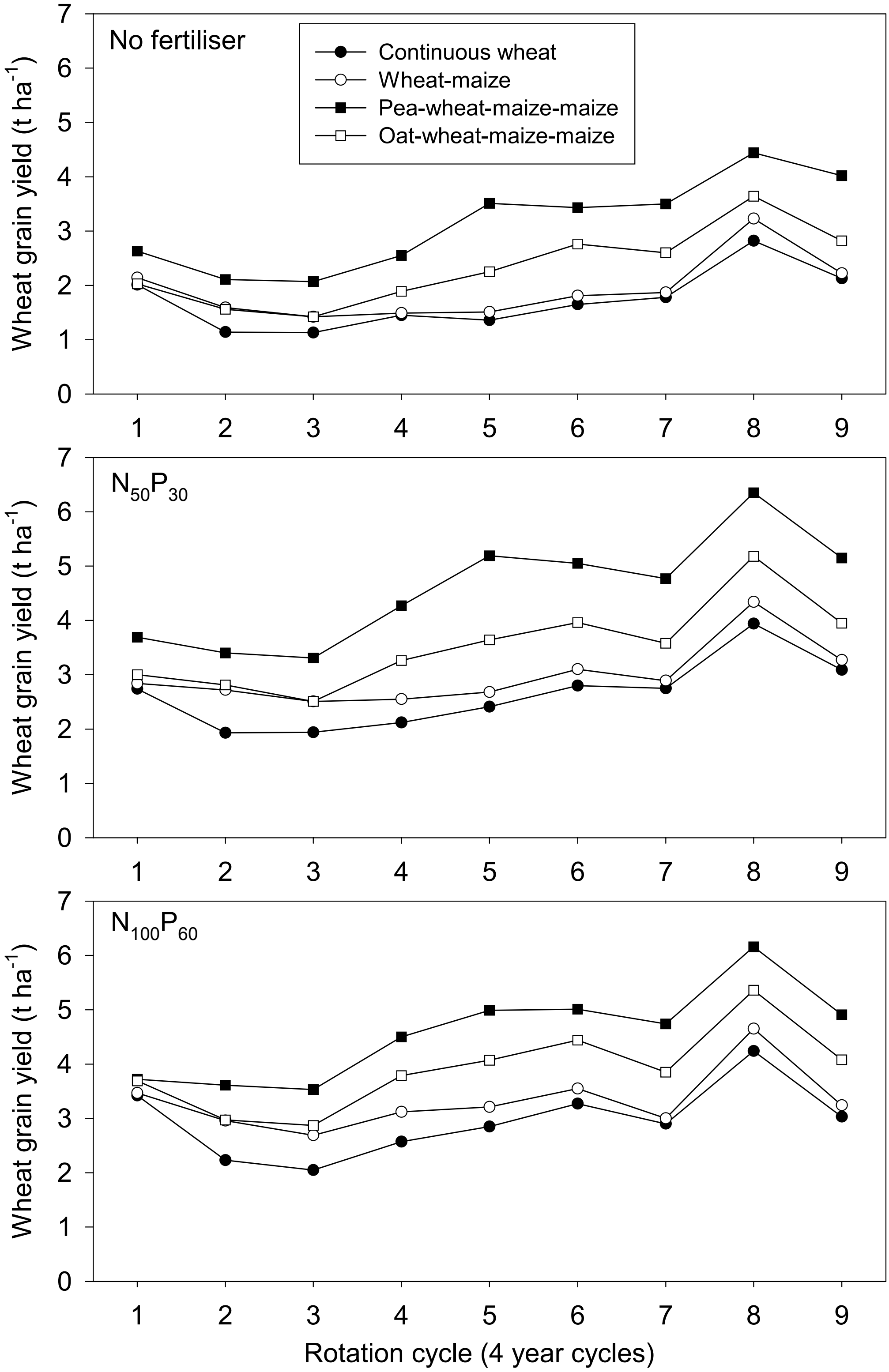

Figure 1 Development in grain yield of wheat in four different crop rotations and three different fertilisation regimes.

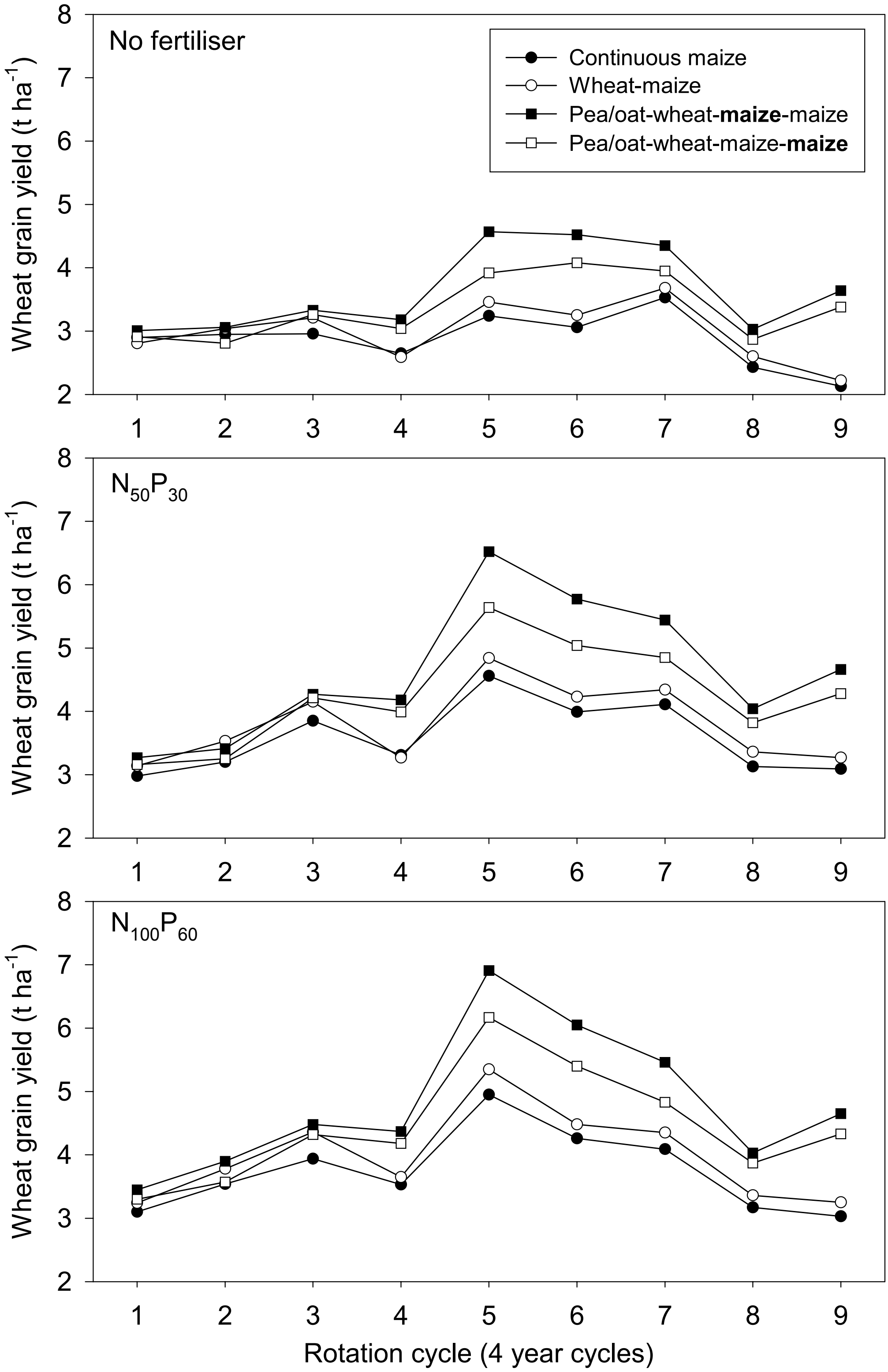

Figure 2 Development in grain yield of maize in different crop rotations and three different fertilisation regimes.

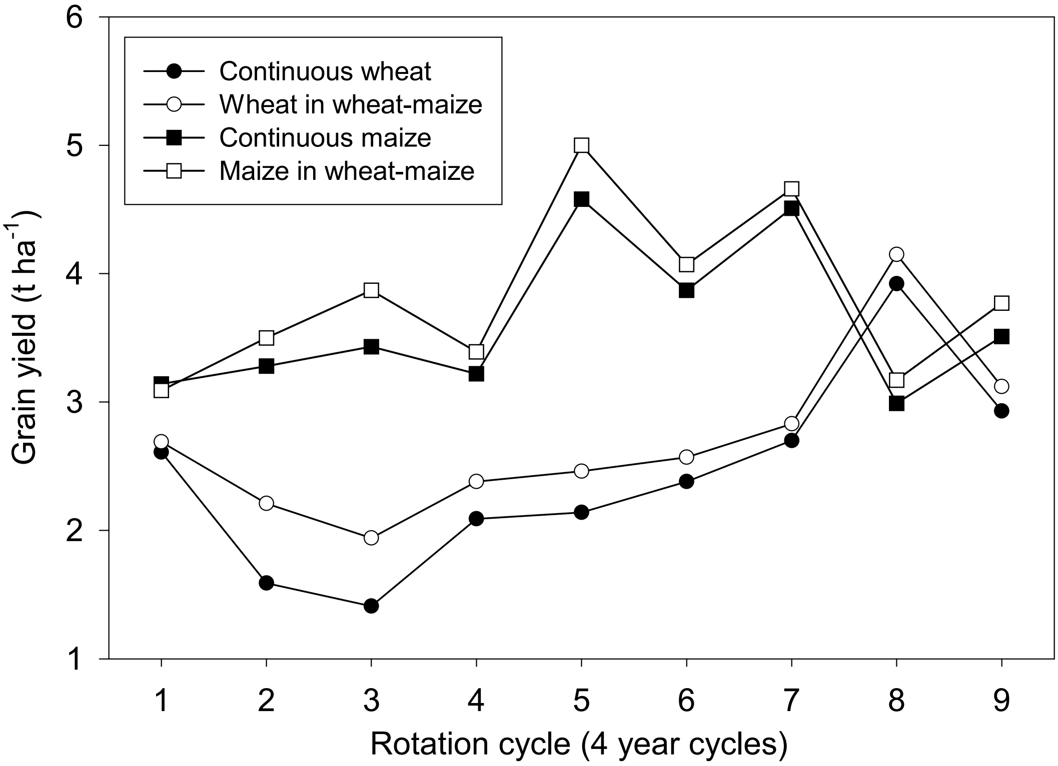

Figure 3 Development in grain yield of wheat and maize under continuous cropping and in the wheat-maize rotation for fertilisation with 40 t ha^{-1} of manure every four years.

The time trends of yields in Figures 1 and 2 show that the rotation effect increases with time. For wheat within the first cycle (1959-1962) only the four-year rotation with peas gave a significantly higher yield at all fertiliser levels compared with continuous wheat. Within the second cycle (1963-1966) all rotations gave significantly higher yields than continuous wheat (Figure 1). Starting with the third cycle of the experiment, the wheat-maize rotation gave lower and lower increase in wheat yield compared to continuous wheat, reaching a level close to continuous cropping in the last cycle (Figures 1 and 3). The wheat yields obtained in continuous wheat or the wheat-maize rotation in the last cycles were lower than those of the first cycle, although within these cycles better varieties were used and the climate was more favourable.

The increase in wheat yield due to the four-year rotation, especially after peas, relative to the continuous cropping generally increased from one cycle to the next. The yield increase was thus about 0.8 t ha^{-1} in the first cycle and about 2.0 t ha^{-1} in the last cycle. The wheat yield in the four-year rotation after oat did not actually differ from continuous wheat in the first cycle, but an increase of about 0.7-1.2 t ha^{-1} was obtained during the last rotation cycles (1983-1986, 1987-1990 and 1991-1994).

The application of manure (40 t ha^{-1} every four years) could not substitute for the positive effect of including a legume crop in the rotation (Table 1).

For maize the development of the effect of rotation on yield over time was largely similar to the effect for wheat, but the yield increase compared with continuous maize is smaller than for wheat, as maize functions better in continuous cropping (Figure 2). Within the first rotation cycles (1952-1962 and 1963-1966) the maize crops in the short rotations were favoured by droughts in 1961-1963, which coincided with spike appearance in maize. This reduced the yields in the rotations relative to the continuous crop. Starting with the third rotation cycle (1967-1971) the maize yield increased in the four-year rotation with legumes regardless of weather. The difference in maize yield between the four-year rotation and continuous maize increased over time. This yield increase was thus about 0.1 t ha^{-1} for maize after wheat in the first cycles and about 0.6-1.5 t ha^{-1} in the last cycles in unfertilised plots. In the fertilised plots the same cycles gave yield increases from about 0.3 t ha^{-1} to 0.8-2.0 t ha^{-1}. Similar results were seen for maize after maize in the four-year rotation, but with slightly lower yields compared to maize after wheat.

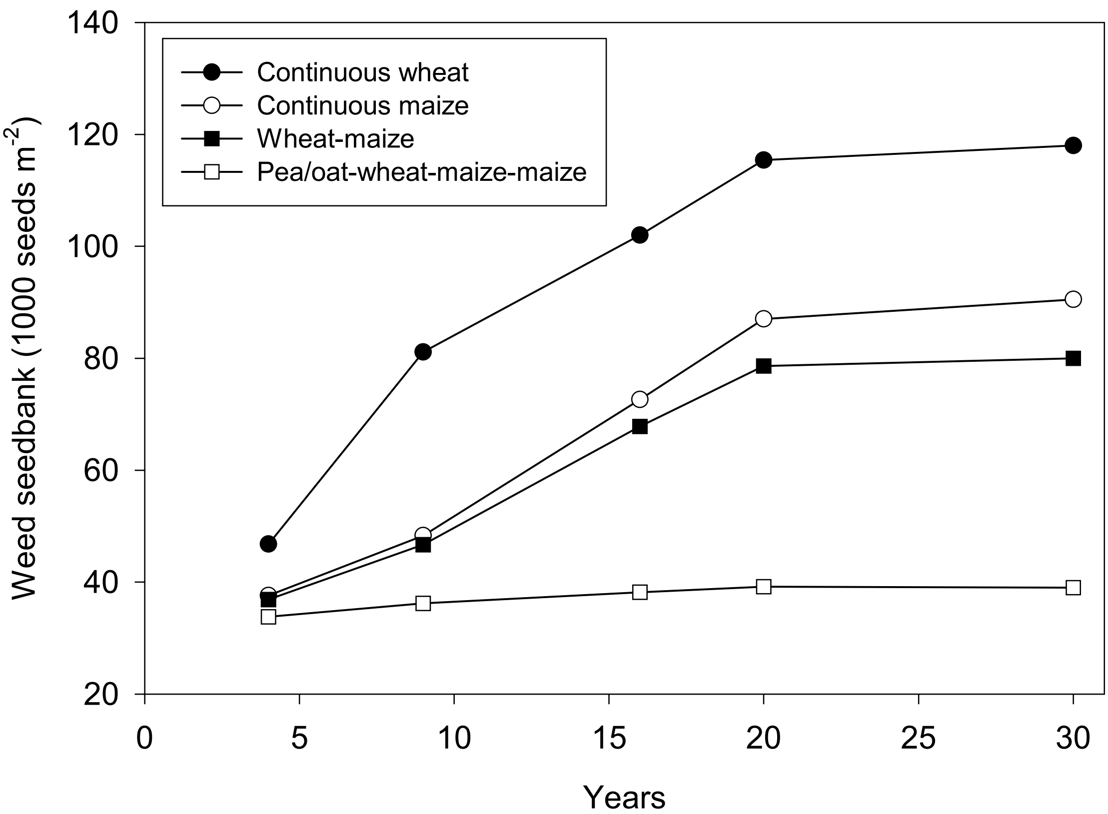

Figure 4 Development in weed seedbank in the different rotations (0-30 cm).

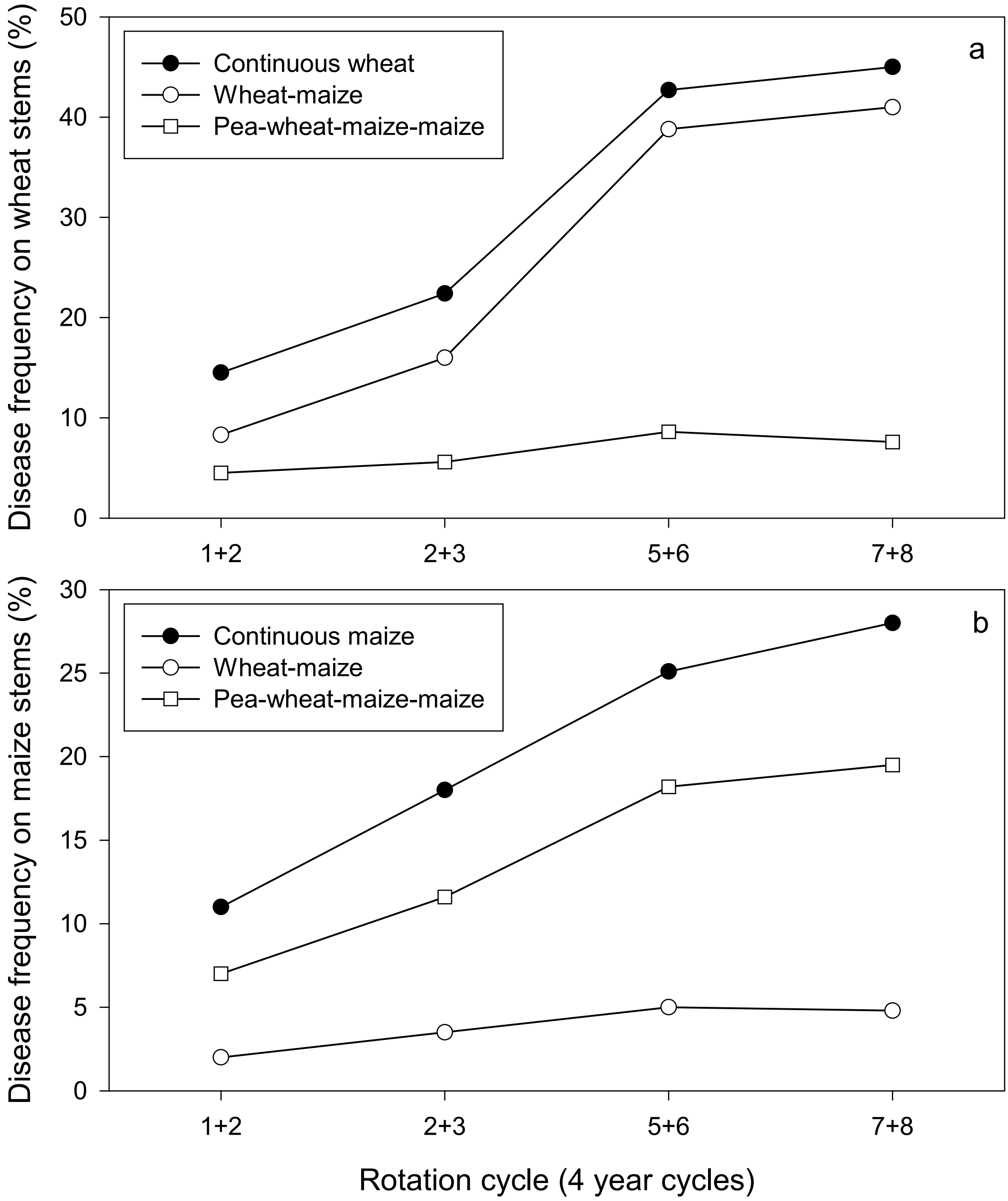

Figure 5 Development in frequency of Fusarium attack on stems and ears.

An analysis of the maize yields of the wheat-maize rotation relative to continuous maize showed that maize yield was only significantly higher in the rotation during the third rotation cycle in all fertiliser treatments (Figures 2 and 3). During the other cycles yield increases were lower despite the use of high yielding hybrids and a generally more favourable climate.

The weed infestation of the experimental plots with continuous wheat and maize increased considerably in comparison to both the starting level and to the four-year rotation (Figure 4). There was a strong infestation with *Veronica hederifolia* in the continuous wheat crop and in the wheat-maize rotation. During the last years the perennial species, including *Convovulus arvesis*, developed in the continuous crops of wheat and maize and in the wheat-maize rotation, as they are difficult to control with herbicides.

The crop rotations also affected the occurrence of diseases. Fusarium attacks on wheat and maize thus became much more prevalent in the continuous wheat and the wheat-maize rotation compared with the four-year rotation (Figure 5). The Fusarium disease is transmitted by the soil and developed to damaging levels in both wheat and maize. After 32 years of experimentation the Fusarium attack increased 3 to 4 times both in continuous wheat and maize and in the wheat-maize rotation.

The results show that the effect of the crop rotation could not be explained by simple effects of fertilisation, but that other factors including weed infestation and disease pressure played a role for the yield levels in both wheat and maize.

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Long-term crop rotations experiments in Latvia

L. Zarina and V. Mikelsons
Priekuli Plant Breeding Station, Zinatnes Street 1a, Priekuli LV-4126, Cesis, Latvia

Summary

A crop rotation experiment has been conducted in Latvia since 1958. The experiment includes 11 different crop rotations and five different fertilisation systems. However, not all crop rotations and fertilisation systems are represented in the field. Only one course of each rotation is represented in any given year. Measurements of soil nutrient contents and of yield and weed infestation were performed every year.

The inclusion of clover in the crop rotations increased soil fertility and yields of cereals and potatoes. The results indicate that crop rotations should include grass-clover a fraction of 20-30%. Grain crops may be included in a fraction of about 50-60% and root crops about 10-20%.

Introduction

The typical crops grown in Latvia are spring barley, spring oat, winter rye, winter wheat, sugar beet, potato and grass-clover mixtures. The actual crops grown and the crop rotation depends on the soil and climate of the specific site. The historical development of crop rotations have been discussed by Rippley (1969) and for Latvian conditions by Lapins and Lejina (1997). The scientific basis of crop rotations in Latvia is based on a number of field experiments (Rubenis, 1975; Lejins *et al.*, 1996).

Both the crop rotation and the fertilisation management are important for maintaining soil fertility and plant nutrition. These factors are also important for soil structure and for the general functioning of the agroecosystem.

This paper describes a field experiment with different crop rotations and fertilisation regimes, which has been conducted in Latvia since 1958 (Mikelsons, 1990).

Materials and methods

A crop rotation experiment was started at Priekuli Plant Breeding station (57°19'N, 25°20'E) in 1958. The experiment included nine different rotations (rotations 1-9). In 1980 two additional rotations were added (rotations 10-11) (Table 1). The clover is red- clover, which is established as an undersown crop in barley. Five different fertilisation treatments are compared with the crop rotations as sub-plots within each fertiliser treatment. The fertiliser treatments are shown in Table 2. Crop rotations 6 to 9 are only included in the fertiliser treatment $N_{132}P_{180}K_{270}$.

Only one course of each rotation is represented in any given year. The size of each crop plot is 100 × 5.9 m. Each plot is sub-divided into 6 harvest plots (replicates).

Table 1 Crop rotations in the experiment.

Number	Length (years)	Crop sequence
1	3	Barley, potato, barley or oat (alternating between rotations)
2	4	Barley, clover, rye, potato
3	6	Barley, clover, barley, rye, barley, potato
4	3	Barley, clover, potato
5	6	Barley, clover, clover, rye, barley, potato
6	2	Black fallow, rye
7	4	Barley, rye, oat, rye
8	8	Rye, rye, rye, rye, clover, clover, clover, clover
9	4	Black fallow, rye, barley, rye
10	2	Potato, barley
11	1	Potato

Table 2 Fertilisation systems in the experiment.

		Applied nutrients (kg ha^{-1})		
Number	**System**	**total-N**	**P**	**K**
1	Unfertilised	0	0	0
2	Stable manure (20 t ha^{-1})	68	38	58
3	NPK	66	90	135
4	Stable manure (20 t ha^{-1}) + NPK	134	128	193
5	2NPK	132	180	270

The experiment is located on a soddy podzolic light loam with 20% clay content in the top soil. The normal mean temperature varies from -6.2 °C in January to 16.7 °C in July. The mean annual rainfall is 691 mm.

Herbicides were not applied during the experiment. No fungicides or insecticides have been sprayed on the crops, but the seeds were treated with fungicides. Weeds have been controlled by harrowing one to two times in the cereals and by ridging in the potatoes.

Cereal grain and straw were removed from the plots, as were harvested potato tubers. For clover crops the first one or two cuts were removed from the plots. The final cut was mulched and incorporated.

Crop yields have been measured, including their contents of N, P and K. Soil samples from 0 to 20 cm have been taken in autumn each year in all plots for determination of pH, and contents of organic matter, P and K. Soil P and K content was determined after extraction with calcium lactate ($C_6H_{10}CaO_6 \times 5H_2O$). Soil pH was determined in a solution of KCl.

Results and discussion

In the year of establishment soil pH was 5.8 to 6.1, organic matter content was 2.1%, P_2O_5 was 80-100 mg kg^{-1}, and K_2O was 100-120 mg kg^{-1}. The initial characteristics of the soils of crop rotations 10 and 11 in 1980 were pH 5.8 to 6.0, organic matter content 1.9%, P_2O_5 135 mg kg^{-1}, and K_2O 150 mg kg^{-1}.

The effect of crop rotation and fertilisation system on potato yield is shown in Table 3. The mean tuber yield (t ha^{-1}) over the period 1986 to 1995 ranged from 4.7 to 8.3 for unfertilised, 13.3 to 30.1 for stable manure, 19.3 to 26.1 for NPK, 26.7-33.4 for stable manure plus NPK, 22.7-26.8 for 2NPK fertilisations systems (Table 1). A comparison of crop rotations 1, 3, 4 and 5 shows that an increasing fraction of clover in the rotation increased the yield for unfertilised, stable manure and NPK systems, whereas there was no effect on yield for the stable manure plus NPK or the 2NPK systems. The fraction of clover in the rotation was 0% in rotation 1, 17% in rotation 3, and 33% in rotations 4 and 5.

Table 3 The influence of crop rotation and fertilisation system on potato tuber yield (t ha^{-1}) as an average of 1986 to 1995.

Crop rotation	Rotation length	Fertilisation system				
		0	Stable manure	NPK	St. manure + NPK	2NPK
1	3	4.7	13.3	19.3	30.7	22.7
4	3	8.1	28.0	23.8	31.7	24.7
3	6	5.9	23.4	22.4	33.4	24.0
5	6	6.6	30.1	26.1	26.7	26.8
10	2	8.3	17.6	17.7	25.2	22.5
11	1	4.7	5.0	5.2	12.7	10.4

The soil organic matter content as an average of samples from 1986 to 1995 is shown in Table 4. The soil organic matter content increased with increasing fertilisation levels, but with a considerably higher increase for the plots receiving stable manure. There were also differences between crop rotations, especially in the unfertilised treatment. Crop rotations, which included a high fraction of clover, had the highest organic matter contents.

The level of soil potassium content increased across the fertilisation systems according the increasing rate of application (compare Tables 5 and 2). The potassium level is lowest in rotations 4 and 5, where large amounts of potassium were removed in the harvested clover and potato crops.

The increasing yield with increasing fraction of clover in the rotation in low-input systems show that the effect of clover for maintaining soil fertility is essential in such systems. From a nutritional point of view this fertility could be substituted by the use of inorganic fertilisers. There was, however, a slightly beneficial effect of clover in the rotation in the 2NPK system. In addition potato yield in the 2NPK system were less than in the stable manure + NPK system, despite the higher nutrient input in the 2NPK system. This suggests that the increase in organic matter content in this system has a positive effect on yields, which seems not to be mediated through nutrient effects.

Table 4 The influence of crop rotation and fertilisation system on organic matter content in top 20 cm of soil (%) as an average of 1986 to 1995.

Crop rotation	Fertilisation system				
	0	Stable manure	NPK	St. manure + NPK	2 NPK
1	1.1	1.6	1.3	1.8	1.4
2	1.2	1.8	1.5	1.9	1.5
3	1.3	1.8	1.2	2.0	1.4
4	1.5	1.7	1.3	1.9	1.5
5	1.2	1.9	1.3	1.9	1.4
6	-	-	-	-	1.1
7	-	-	-	-	1.3
8	-	-	-	-	1.4
9	-	-	-	-	1.3
10	1.3	1.8	1.5	1.8	1.6
11	1.1	1.6	1.4	1.4	1.4

Table 5 The influence of crop rotation and fertilisation system on content of potassium in autumn 1995 (mg K_2O kg^{-1}).

Crop rotation	Fertilisation system				
	0	Stable manure	NPK	St. manure + NPK	2 NPK
1	75	204	275	344	388
2	60	161	226	345	382
3	59	175	268	350	385
4	63	141	218	335	354
5	48	162	145	253	275
6	-	-	-	-	256
7	-	-	-	-	340
8	-	-	-	-	308
9	-	-	-	-	348
10	91	137	214	223	241
11	94	207	172	229	253

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Whole crop rotation and farm studies

Testing a Stockless Arable Organic Rotation on a Fertile Soil

W. F. Cormack
ADAS Terrington, Terrington St. Clement, King's Lynn, Norfolk PE34 4PW, UK

Summary

The conversion of 10 ha of silty clay loam soil to a stockless arable organic rotation began in 1990. Conversion was two years of red clover, which was cut and left as a mulch, about four times per year. Following conversion, a sequence of potatoes, winter wheat, spring beans and spring wheat was grown. Organic crops have yielded well, price premiums have been good and profitability better than from a conventional arable rotation. This is particularly encouraging when the comparison has been made on some of the most productive arable land in the UK. Soil available potassium and phosphorus look to be stabilising at a level non-limiting to crop production. Results to date suggest that the rotation can fix sufficient nitrogen to give satisfactory crop yields, even following a single year of red clover in the second cycle of the rotation. However, in the absence of full data on nitrogen cycling, more years' data is needed to confirm this. Soil-borne problems are causing some sustainability concerns. Perennial weeds, e.g. *Circium arvense* (creeping thistle) and *Elytrigia repens* (couch grass) are increasing. Potatoes may need to be grown less frequently to prevent increase in *Globodera rostochiensis* / *G. pallida* (Potato Cyst Nematode). *Ditylenchus dipsaci* (Stem nematode) affected red clover in 1998. None of these problems should be fatal to the system but their containment will necessitate changes to cropping and husbandry as the soil continues to equilibriate to organic farming methods.

Introduction

The majority of organic farming in England and Wales is on mixed or livestock units in central and western areas. Many of these farms grow arable crops. However uptake of organic farming in predominantly arable eastern areas has been minimal. Many farms in the east have no livestock expertise or facilities and would have to depend on a stockless rotation. In the late 1980's the only UK experience with stockless systems was a small plot experiment at Elm Farm Research Centre (Stopes & Millington, 1992). This was on a mixed farm and followed a grass ley. To encourage the expansion into arable areas, both to meet demand and for environmental benefit, the UK Ministry of Agriculture Fisheries and Food (MAFF) initiated an evaluation of a stockless system on a fertile soil at ADAS Terrington.

The overall objectives of the work are to assess the economics of stockless arable organic production for MAFF to use in policy setting, to research identified limitations to sustainability and to demonstrate to farmers and advisers.

The study is in three parts. The main system evaluation is on a field scale to allow the use of normal farm machinery and give credibility to potential converters to organic. This is complemented by a number of small plot replicated experiments, for example comparing legumes for fertility building (Cormack, 1996). The third element of the work is an economic evaluation of ten commercial organic farms. These are on lighter, less fertile soils. This paper reports results from the main system study only. It concentrates on crop yields, profitability and sustainability of nutrient supply.

Materials and methods

ADAS Terrington Research Farm is in Norfolk, in the east of England (0°17'E, 52°44'N). The soil is a stoneless silty clay loam of the Agney soil series (Hodge *et al.*, 1984).

Terrington Research Farm is at a uniform altitude of 3 m above mean sea level. It is located in an area of reclaimed marshland, near the Wash. The soil is derived from marine alluvium and has a naturally high pH of around 7.5. It is retentive of water and nutrients. In the area it is intensively cultivated for arable and field vegetable crops. Rainfall averages 584 mm, evenly distributed throughout the year although recent years have tended to be well below average and have an uneven distribution with time. The farm has been cropped in an arable rotation for at least 50 years. The current conventional crop rotation includes winter wheat, potatoes, sugar beet, and linseed. Soil organic matter is typical for the soil type at around 2.5 % (Johnson & Prince, 1991).

The conversion of 10 hectares to a stockless arable organic rotation, to UKROFS standards (Anon, 1991), began in the autumn of 1990. The ten hectares were divided into five equal "plots". Conversion was phased-in over three years and was completed in autumn 1994. Conversion was two years of red clover cut and left as a mulch (Cormack, 1997). The crop rotation was a sequence of potatoes (cv. Santé), winter wheat (cv. Hereward), spring beans (*Vicia faba,* cv. Alfred) and spring wheat (cv. Axona) undersown with red clover. The red clover was grown and mulched for one year and the sequence repeated.

Cover crops of stubble turnips (*Brassica rapa*) were grown between winter wheat and beans and between beans and the undersown spring wheat. These were generally sown in early September and ploughed-in in January. Turnips were chosen, as in earlier work at Terrington (Harrison *et al.*, 1996), of a range of crops tested, they showed a good uptake of nitrogen and were more frost resistant than the alternatives.

All operations were done with normal farm tractors and machinery. Crop yields were assessed by taking the average from six cuts, each of 20 m by 2 m, with a Sampo Rosenlew 2010 plot combine harvester for cereals and beans, and six hand-harvested areas, each of 2 rows (1.8 m) by 10 m for potatoes. Yields measured in this way were probably around 10 % greater than would be realised using farm machinery. Prices were determined from actual sale prices. All operations were recorded and costed to allow gross margins (crop revenue plus any arable area aid payment, minus variable costs) to be calculated for each crop. Variable costs included seed, approved pesticides and marketing expenses. The financial data were compared with the returns from the conventional Terrington crop rotation.

Soil was sampled before and after conversion, and annually in autumn post-conversion. Available P and K, and organic matter were measured. Total soil nitrogen and soil aggregate stability were also measured but are not reported here (Cormack, 1997). Clover yield and nitrogen content were assessed from five quadrats, each of 0.5 m^2, cut in each plot just prior to each mulching. Nutrient content of all harvested produce was assessed and crop offtake of N, P and K calculated. It was outside the scope of this project to assess the full nitrogen cycle. All analyses were according to standard methods (Anon, 1984; Anon, 1986).
Statistical analyses have not been applied to these data as the main study was unreplicated.

Results and discussion

Red clover grew well as a conversion crop, average two-year dry matter yield was 19.4 t ha^{-1} and total nitrogen recorded in the mulched red clover foliage averaged 682 kg N ha^{-1} (Cormack, 1997).

Table 1 Potato yields, prices and gross margins.

	Total yield t ha^{-1}	Saleable yield (45-85 mm) t ha-1	Price GBP t-1	Gross margin GBP ha-1
1993	38.3	18.6	115	1329
1994	42.5	36.0	320	10344
1995	26.4	17.2	300	4278
1996	46.6	40.2	175	6160
1997	37.5	29.1	230	5720
1998	31.7	14.7	435	5350

Potatoes

Yields of potatoes have been rather variable, mainly reflecting rainfall patterns (Table 1). The low yields of saleable tubers in 1993 and 1998 were due to a large proportion of rejects from slug (*Agriolimax reticulatus*) damage in these wet seasons. The very dry summer of 1995 led to a large proportion of under-sized tubers. The summer of 1996 was also dry but rain in late July prevented a similar situation. Potato blight (*Phytophthora infestans*) necessitated early defoliation and a reduced yield in 1997. Prices were very variable, reflecting under-supply in 1994, 1995 and 1998, and over-supply in the other years.

Table 2 Winter wheat yields, prices and crop gross margins.

	Yield at 85% DM t ha-1	Protein %	Price GBP t-1	Gross margin GBP ha-1
1994	6.3	9.6	200	1344
1995	6.7	8.3	175	1398
1996	9.8	9.1	200	2090
1997	5.4	8.3	165	1081
1998	7.9	9.1	160	1464

Winter wheat

Winter wheat crops have established well with minimal pest and disease incidence and have given good yields (Table 2). Protein content has generally been too low to achieve top milling quality prices. Since 1996, the market for organic feed grain has been strong, with the price almost the same as for milling. Wheat yields in 1996, whether conventional or organic, were well above average in many parts of the UK. The average yield of 7.2 t ha^{-1} is well above expectation for organic production on lighter soil types in the UK (Lampkin & Measures, 1999), illustrating the water and nutrient retention properties of the silty clay loam soil.

Table 3 Spring bean yields, prices and crop gross margins.

	Yield at 85% DM t ha^{-1}	Protein %	Price GBP t^{-1}	Gross margin GBP ha^{-1}
1995	2.9	22.3	150	685
1996	3.9	23.4	200	940
1997	2.4	22.3	180	676
1998	3.2	21.7	170	776

Beans

Bean yields have been modest (Table 3). Disease has not been a problem.

Table 4. Spring wheat (undersown) yield, price and crop gross margin.

	Yield at 85% DM t ha^{-1}	Protein %	Price GBP t^{-1}	Gross margin GBP ha^{-1}
1996	4.3	8.7	200	1100
1997	4.0	9.0	180	787
1998	4.0	8.3	160	689

Spring wheat (undersown)

Spring wheat has yielded an average of 4.1 t ha^{-1} (Table 4).

Economic evaluation

On average, yields of winter wheat have been 82% of conventional and potatoes have yielded 61% of conventional. With the exception of potatoes in 1998, good price premiums and lower variable costs have consistently given greater gross margins from organic potatoes and winter wheat, despite lower yields. When the two systems were projected to a notional farm of 120 ha, typical for the area, using averaged data up to 1998 harvest, and allowance made for the UK Organic Aid Scheme, Set Aside and Arable Area Aid Payments, the organic system had a greater farm gross margin (GBP 183,120 organic versus GBP 177,720 conventional). In contrast to these excellent results, data from the linked study of ten commercial farms showed an overall farm gross margin only equivalent to conventional. The main difference was that cereal crop yields were significantly lower on the lighter soils of these farms.

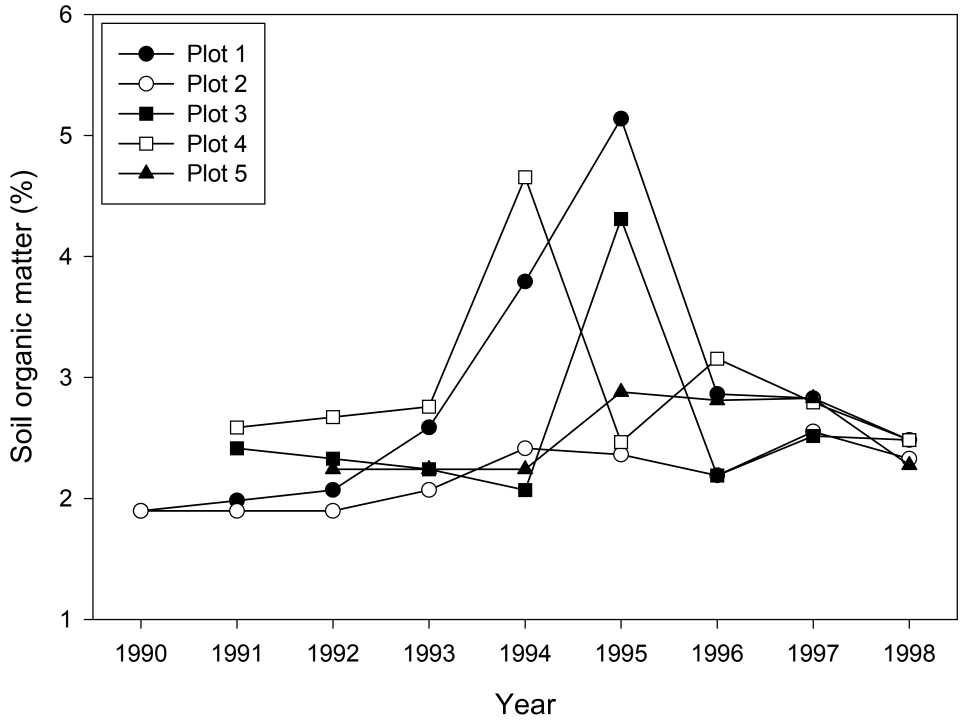

Figure 1 Development in soil organic matter in 0-15 cm depth in the different plots.

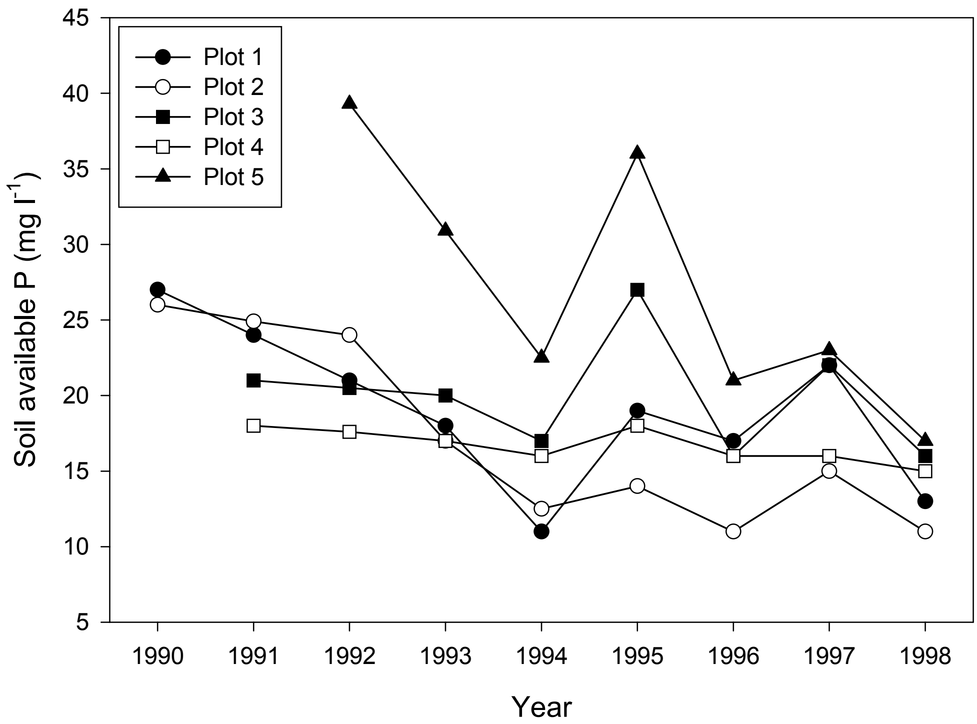

Figure 2 Development in soil available phosphorus in 0-15 cm depth in the different plots.

Soil organic matter

Soil organic matter was between 2 and 2.5% before conversion (Figure 1). It rose to around 4.5% in three plots but showed little change in the other two. This increase was probably caused by sampling/analytical error as it is unlikely that two years of red clover would give such a large increase in organic matter. By 1996 it had fallen back to around 2.5 % in all plots and has remained there since. In comparison with the previously practiced conventional rotation, the only significant increase in organic matter input to the soil is that from the red clover and chopped wheat straw, therefore a large permanent increase was not expected.

Soil available phosphorus content

Soil available phosphorus declined from 1990 to 1994 (Figure 2). If that rate of decline had continued, soil levels would soon have been limiting crop growth and yield. As a result, it was decided that an input of an approved phosphorus fertiliser was necessary. Aluminium calcium phosphate (14% P) has since been applied at the same point in the rotation, after harvest of the beans, to plots 1, 2, 3 and 4 at 625 kg ha^{-1}. Plot five will be treated in 1999. This fertiliser was chosen as it should be more available in our alkaline soil. Subsequent soil analyses suggest that the earlier decline in soil available phosphorus has slowed, although there are clearly seasonal effects in availability. There is no indication that the application of fertiliser has yet had a significant effect on available P. It is probable that the earlier decline was due to the utilisation of the large surplus inherited from conventional farming, and the reaching of an equilibrium level under organic husbandry. Available P is currently at around 15 mg l^{-1}. This is on the border of ADAS "Index" 1 to 2 (Anon, 1994), having fallen from a starting point of between 18 to 39 mg l^{-1} depending on the plot. Index 1 to 2 would not be classed as limiting to crop yield in a conventional system. Crop yields and nutrient contents suggest that it is not limiting in this organic rotation.

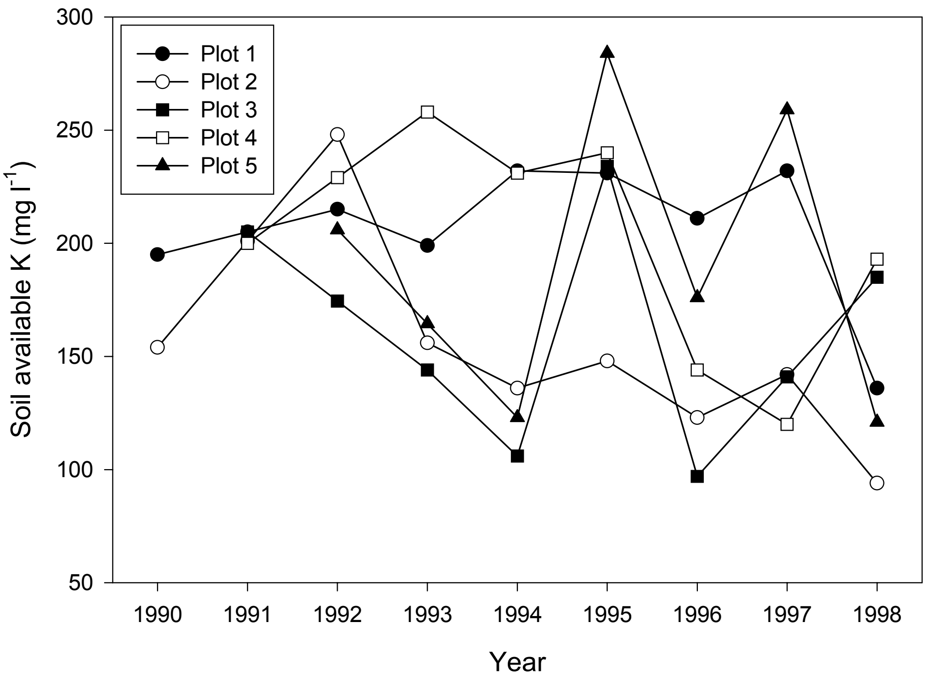

Figure 3 Development in soil available potassium in 0-15 cm depth in the different plots.

Soil available potassium content

Soil available potassium levels have been relatively stable, although again with some marked variation between years (Figure 3). Levels currently range between 94 and 193 mg l^{-1}, again Index 1 to 2, and not normally limiting to yield in a conventional system. The soil is showing a great capacity to supply K despite none having been applied for up to nine years.

Crop nutrient uptake

Measurements of N fixation, leaching and other losses are outside the scope of this project so it was not possible to produce precise data on nitrogen cycling. However, using crop yield and N content data, an estimate can be made. Nitrogen fixation has been shown to be well related to dry matter yield in red clover and grain yield in beans (Köpke, 1995). Applying these relationships to the Terrington data for plot one, the first to complete a full crop rotation, indicates that in the first cycle after the two year conversion, the total nitrogen supplied by the two year conversion crop of clover (660 kg ha^{-1}) was more than that required by the following four crops (Figure 4). For the second crop rotation, 238 kg ha^{-1} of nitrogen from one year of clover will be available. This should be just sufficient to compensate for the likely net N requirement of the next four crops. Similar data have been recorded from the other four plots. This does not allow for leaching and other losses of nitrogen, or for atmospheric input, but does give an indication that the rotation may just be sustainable for nitrogen. This was one of the main sustainability doubts when the project was being planned.
Cumulative offtake of phosphorus, to date, on plot one, has been 67 kg ha^{-1}, and of potassium 300 kg ha^{-1}. The majority of the potassium, 229 kg ha^{-1}, was in potato tubers. Crop yields, nutrient contents and soil available nutrient contents all suggest that the soil is currently able to provide these levels of nutrients and that it will probably last several years before further additions from fertiliser or compost needs to be considered.

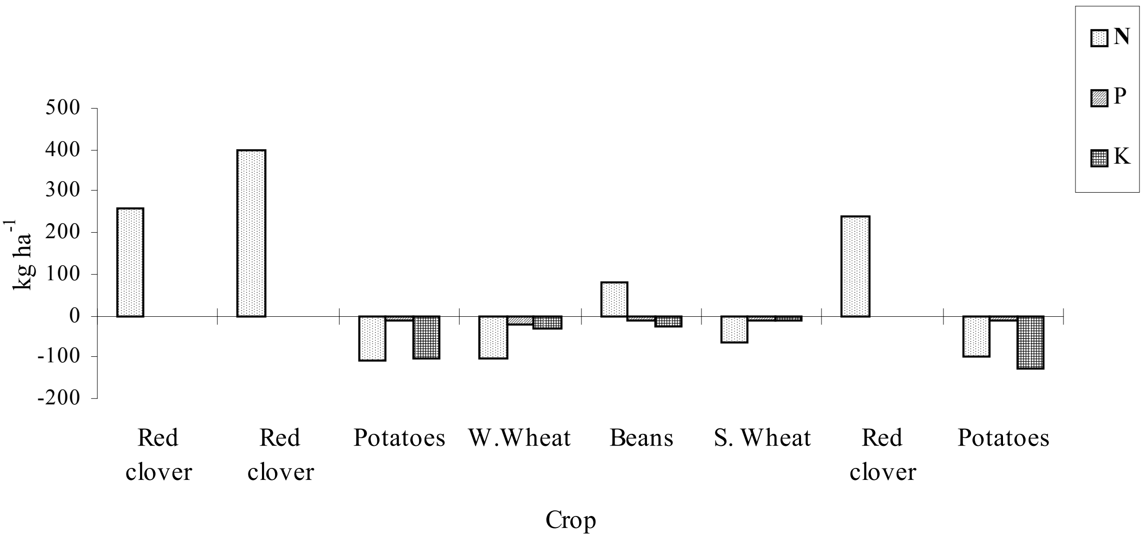

Figure 4 Estimated N fixation by legumes and N, P and K offtake in crops for plot 1.

Other limitations to sustainability

Annual weeds have increased but have generally been adequately controlled. Perennial weeds, particularly creeping thistle (*Circium arvense*) and couch grass (*Elytrigia repens*), are increasing. These may become a limitation to profitability and improved control must be a priority for the next phase of the experiment.

UK Organic Regulations allow potatoes to be grown as frequently as one year in four. At this frequency, potato cyst nematode (*Globodera rostochiensis and G. pallida*), if present, may still progressively increase in population and eventually seriously reduce yield. Rate of decline under non-host crops will vary according to soil type but it could need as many as six years between potato crops to be sure of no long term increase in population. Very low or undetectable populations exist in the soil at Terrington. A detailed annual monitoring programme has been started to measure changes and better predict what frequency this site and rotation can sustain. Vegetables are being introduced as an alternative to potatoes to allow longer intervals between crops.

Stem nematode (*Ditylenchus dipsaci*) was discovered to be the cause of poor growth in patches in red clover in spring 1998. The nematode is probably of the Red Clover Race, but tests are not complete. The clover in the patches later grew normally with drier and warmer conditions in summer 1998. Soil analyses show that stem nematode was first recorded in 1993. It may have been present earlier at undetectable levels or it may have been introduced on purchased red clover seed sown for conversion crops. From 1999, red clover has been replaced by white clover and lucerne as these should be resistant to the Red Clover Race.

Acknowledgments

The work was funded by the UK Ministry of Agriculture Fisheries and Food. Thanks are also due to the members of our Steering group, to the Linked-farmers and to all those in ADAS who have contributed to the work.

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Nutrient balances and yields during conversion to organic farming in two crop rotation systems

Å. Asdal [1] and A.K. Bakken [2]
The Norwegian Crop Research Institute
[1] Apelsvoll Research Centre, division Landvik, N-4886 Grimstad, Norway
[2] Kvithamar Research Centre, N-7500 Stjørdal, Norway

Summary

Two long-term studies on conversion to organic farming were established in 1993 at the Norwegian Crop Research Institute. The one located at Landvik simulates a cash crop production system fertilised with household compost, and the one located at Kvithamar simulates a dairy farm system. Reference parts of the fields are monitored for fertiliser inputs, yields, nutrient balances and available nutrients in the soil.

At Landvik the seed-growing fields have given excellent yields. Carrots and potatoes have also returned high yields, but they have been more vulnerable to suboptimal weather conditions and pests. Accounts of inputs and outputs show quite a good balance for N and P, but there is a significant shortage of K.

At Kvithamar the yields of all crops have varied between years. The average yields obtained in ley have been satisfactory according to the standards set by organic farmers in the district, whereas the yield from barley has been low. Swede and oats have given from satisfactory to low yields. The nutrient accounts reveal that the input of N has been higher than the output, whereas the account balances for P and K were negative.

Although the pool of potassium in the soil in both systems were depleted by more than 300 kg K ha^{-1} during a 5 year period, the present supply still seems to meet the demand of the plants.

Introduction

More than 1% of the agricultural land in Norway is now farmed organically (DEBIO, 1998). During the last decade, The Ministry of Agriculture has supported the conversion to organic farming by funding research on the agronomic sides of the process. In 1993 the Ministry through The Norwegian Research Council (previous NLVF), the Norwegian Crop Research Institute and the Agricultural University established three cropping systems. They were meant to be areas for studies of soil chemistry and biology, plant performance, yield potentials and nutrient balances during and after conversion from conventional to organic farming (Haraldsen, 1993). A brief description of two of them and the yields and plant nutrient accounts for the first five years will be presented here.

Materials and methods

Soil, cropping history and climate at field sites

The soils at the two study sites (Landvik and Kvithamar) are both of marine origin. At Landvik it is classified as an imperfectly to poorly drained silt loam with 3.3% organic C in the top soil and at Kvithamar as a poorly drained silty clay loam with 4.2% organic C in the topsoil (Haraldsen *et al.*, 1994; Sveistrup *et al.*, 1994).

Until the start of the conversion process in 1993, the study area at Landvik (58°N, 8°E) had been managed in a 8-year rotation of four years with different vegetables, mainly cabbage (*Brassica oleracea* L.) and carrots (*Daucus carota* L.), and later four years with ley, dominated by timothy *(Phleum pratense* L.). At Kvithamar (63°N, 11°E) there had been a crop rotation of barley (*Hordeum vulgare*) and ley dominated by timothy and meadow fescue (*Festuca pratensis* Huds.). No farmyard manure or other kinds of organic fertiliser have been applied during the last 20 years before conversion, and NPK mineral-fertilisers have been applied regularily.

At Landvik the annual precipitation is 1230 mm, and there are 202 days per year with a mean temperature higher than 5.0°C (normal 1961-90). The corresponding figures for Kvithamar are 892 mm and 182 days, respectively.

Crop rotations and systems lay-out

The systems lay-out is based on the Danish method of system research (Heidmann, 1988). Both fields are split into six main plots for the rotation of different crops. Each main plot is divided into one reference-plot and one plot for experimental purposes. The reference plot is farmed according to organic principles, and there is a registration program for fertilizer inputs, yields, nutrient balance and nutrient contents in the soil. The data presented are from these reference-plots. The Kvithamar system covers an area of 2.3 ha, and the Landvik system an area of 1.0 ha.

In 1994, 6-year crop rotations were initiated at both sites (Table 1). At Landvik a cash crop system with no use of farmyard manure is simulated. The crops are fertilised with composted organic household waste. The straw is always removed after seed-harvest. Cabbage was replaced by lettuce from 1997 because the latter has a lower nutrient demand.

Table 1 Crop rotation in two organically farmed systems at The Norwegian Crop Research Institute, Landvik and Kvithamar from 1994 to 1999.

Course	Landvik	Kvithamar
1	Spring wheat undersown with grass	Spring barley undersown with timothy, meadow fescue, ryegrass, red clover, white clover, alsike clover
2	Seed production of timothy/clover*	Clover ley
3	Seed production of timothy/clover	Clover ley
4	Potatoes	Clover ley
5	Cabbage/Lettuce	Swede
6	Carrot	Oats or barley

* Alsike clover was sown in 1993-1996, white clover in 1997.

The Kvithamar system simulates a dairy farm. All crops are fertilised with farmyard manure. The straw from the undersown barley is taken out of the system, whereas the straw from the cereals in the 6^{th} course of the rotation and the leaves from the swede are left in the system.

Nutrient inputs

Composted organic household waste has been used as an external nutrient source on the fields at Landvik. In 1996 the Landvik system was declared as "fields for organic production" according to the Norwegian control system for organic farming. This implies a maximum limit of 100 kg N ha^{-1} applied in compost from non-organic origin. This amount has been supplemented with composted waste from the system itself, which can be used with no limitations. No fertiliser was applied to the seed crops at Landvik.

At Kvithamar farmyard manure corresponding to 60 kg N ha^{-1} has been applied every year in the rotation.

Nitrogen-fixation at both experimental sites has been estimated according to a formula based on experiments and experience (Nesheim, 1994):

- N_{fix} (kg ha^{-1}) = $yield_{DM}$ × %clover × N-content in clover × $\%N_{symb}$ × 1,27 10^{-5}
- The percentage of clover is based on a visual estimation of the plant stand. The N-content in red clover and alsike-clover was set to 3.14% in the first harvest and 2.91% in the second harvest. $\%N_{symb}$ is a correction for readily available N given in farmyard manure at Kvithamar. $\%N_{symb}$ = 92,3 - 0,26 × N_{min}, where N_{min} is mineral nitrogen applied in farmyard manure (kg N ha^{-1}).

Results and discussion

N-fixation

At Landvik and Kvithamar 28 and 56%, respectively, of the total input of N over 5 years were from N-fixation (Table 2). At both sites the first year ley/seed production fields gave the highest yields of biologically fixed N (Tables 4 and 5). The decrease in fixation with time was related to a decrease in the proportion of clover in the leys. In three out of five years at Landvik there was 80% or more clover in the first year crop, whereas the clover content in the second year crop was as low as 5-15% (Table 4) (Aamlid, 1999). Low persistence of alsike clover was probably caused by the late harvest of clover-seeds, which did not allow any regrowth of clover in the autumn.

Table 2 Accumulated nutrient balances (kg ha^{-1}) for the years 1994-1998 in two 6-year crop rotation systems located at Landvik and Kvithamar. Means of the 6 fields constituting each of the two systems are given.

	Landvik	Kvithamar
Nutrient	**Balance (supplied - removed)**	**Balance (supplied - removed)**
Nitrogen	141 (459* - 317)	111 (523* - 412)
Phosphorus	33 (95 - 62)	-25 (44 - 69)
Potassium	- 367 (153 - 519)	-300 (228 - 527)

*) 127 and 292 kg were from N-fixation at Landvik and Kvithamar, respectively.

Table 3 Nutrient balances (kg ha^{-1} yr^{-1}) for the different crops in two organically farmed crop rotation systems at The Norwegian Crop Research Institute, Landvik and Kvithamar for the years 1994-1998.

System and crop	Means for	N	P	K
Landvik				
1. year seed crop	5 fields	61	- 8	- 106
2. year seed crop	4 fields	- 18	- 7	- 62
Wheat (undersown)	5 fields	- 19	0	- 23
Cabbage	3 fields	129	46	- 93
Carrots	5 fields	20	8	- 104
Potatoes	5 fields	27	11	- 82
Lettuce	2 fields	56	20	- 3
Kvithamar				
Barley (undersown)	5 fields	32	2	36
1st year ley	7 fields	41	- 13	- 175
2nd year ley	5 fields	7	- 11	- 118
3rd year ley	3 fields	7	- 12	- 102
Swede	5 fields	46	8	9
Oat	5 fields	- 17	- 5	19

Table 4 Nitrogen balance (kg N ha^{-1} yr^{-1}) and clover content for the two crops with N-fixation at Landvik, which is first and second year ley with timothy and clover seed production.

	First year		Second year		Two years
Year	% clover	Balance	% clover	Balance	Balance
1994+95	80	85	15	-29	55
1995+96	50	25	5	-21	4
1996+97	90	74	10	-10	64
1997+98	98	124	10	-9	115
Average	80	77	10	-18	59

Table 5 Estimated yearly nitrogen input (kg N ha^{-1} yr^{-1}) from N-fixation in a 6-year crop rotation system with barley undersown with grass/clover, 3 year clover ley (cut twice each year), swede and oats. Means (± SD) for the years 1994-1998 are given.

Crop	Spring growth	Regrowth	Total
Barley undersown with grass and clover	10 ± 6		10
1st year ley	91 ± 53	48 ± 18	139
2nd year ley	50 ± 26	35 ± 18	85
3rd year ley	44 ± 25	30 ± 26	74

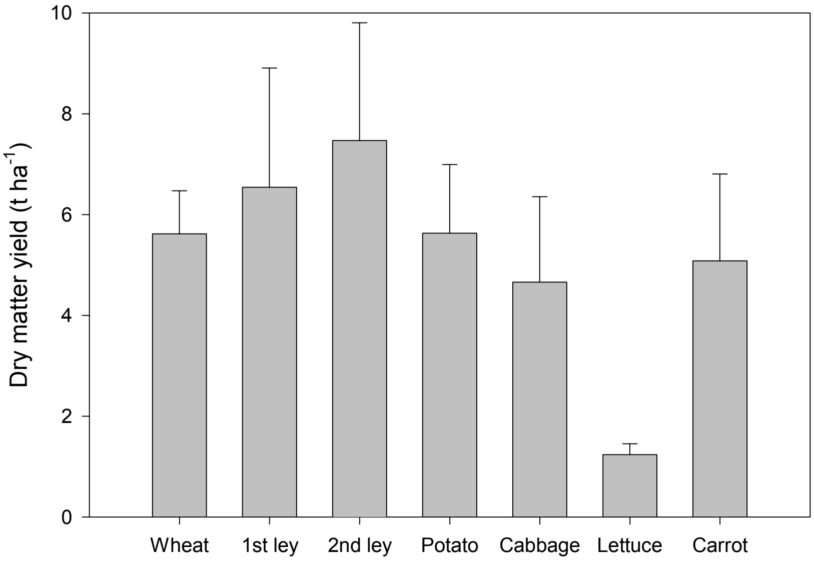

Figure 1 Dry matter yields taken out of a 6-year crop rotation system located at The Norwegian Crop Research Institute, Landvik. Means for the years 1994 -1998 with standard deviations are given.

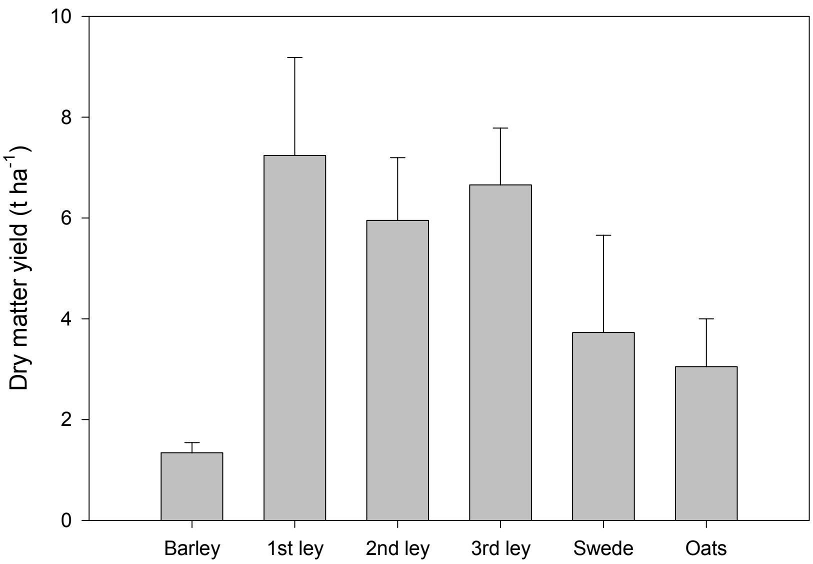

Figure 2 Dry matter yields taken out of a 6-year crop rotation system located at The Norwegian Crop Research Institute, Kvithamar. Means for the years 1994-1998 with standard deviations are given. The straw was removed from fields with barley, but its weight is not included in the figure for barley yield.

The second year ley was dominated by timothy that yielded quite well (Figure 1), partly because of the significant N surplus accumulated by the clover the previous year (Table 4). Due to limitations to the use of non-organic compost implemented from 1996 onwards, the importance of effective nitrogen fixation in the Landvik system will increase.

Yields

Cereal yields were quite stable for wheat and within 65 to 85% of the average yields in conventional farming in the Landvik district (Figure 1; Eltun, 1996). At Kvithamar, the mean yields for barley and oats have been 1.5 and 3.5 t ha^{-1} (Figure 2), which for oats are rather low and for barley very low compared to yields obtained in conventional farming. As discussed by Haraldsen *et al.* (1999), the soil below the plough layer is very dense at Kvithamar, and root growth might have been severely restricted. The soil conditions are furthermore far from optimal regarding N-mineralisation and N-loss, especially under wet and cold weather conditions. Low yields from cereals might consequently have been caused by a shortage of plant available N, even if the nutrient account for N shows a positive balance for undersown barley (Table 3).

The seed production fields gave excellent yields, sometimes higher than in conventional farming (data not shown). Alsike clover was the major component in the first ley year, and the seed-yields were stable at about the same level as in conventional farming. The second year crop was dominated by timothy. Seed yields of timothy after a clover-rich first year ley were high, and sometimes higher than for conventional farming. This is partly due to the fact that lodging never occurred in the organic seed-crops.

The yields of vegetables were variable at both Landvik and Kvithamar (Figures 1 and 2) and highly affected by weather-conditions and pests. In some years difficult weather conditions in the spring and early attack of potato blight reduced the yields in potatoes. In the best years the potato yields were almost as high as in conventional farming. The yields of cabbage in the three first years were high. This is, however, a nitrogen-demanding crop and limitations to the use of external compost from non-organic sources caused change from cabbage to lettuce from 1997 and onwards.

The carrots were also vulnerable to climatic conditions and pests. Two years of excellent yields in the beginning of the study were not repeated. Problems during seed bed preparation with resulting weed-problems gave poor stands of carrots and reduced yields significantly.

Although of some importance, pests were not the main explanation for the rather low and variable yields of swede at Kvithamar (Figure 2). The demand for N might not have been met, and the harrowing aimed at weed control and soil aeration were unfortunately left out or badly timed in some years.

Nutrient balances

As regards nitrogen, the input from compost, farmyard manure and N-fixation was higher than the removal in the yields in both systems (Table 2). Haraldsen *et al.* (1999) still suggest that the actual balance is close to zero when estimated leaching is taken into account. Although the input of N from biological fixation was considerably higher at Kvithamar than at Landvik both in absolute and relative terms, it was of importance for the total balance at both sites (Tables 2 and 3). The remarkably high surplus that occured on the cabbage and lettuce fields at Landvik (Table 3) was due to a high supply of compost in some years before the limitations to the input was set in 1996. The total surplus of phosphorus at Landvik is also partly the result of the high supply of compost to cabbage and lettuce (Tables 2 and 3). Nearly twice as much was supplied of this nutrient at Landvik as at Kvithamar, whereas almost the same amount was taken out by the yields at the two sites (Table 2).

The K-account shows big deficits in both cropping systems (Table 2). More than 70% of the potassium taken out at Landvik and more than 50% of the potassium taken out at Kvithamar were from soil reserves (Table 2). According to plant analyses, the total supply from fertilisers and soils seem to have been sufficient for all crops (data not shown). Soil analyses to be undertaken in autumn 1999 will reveal whether the pool of K in the soil has been significantly and seriously depleted. At Kvithamar most of the K taken out has been in yields from ley, whereas yields from cabbage, carrots, potatoes and seed leys have all contributed to the negative balance at Landvik (Table 3).

Conclusions

With the exception of undersown barley at Kvithamar, all crops have returned what we regard as acceptable yields in an organically farmed system, for at least one of the five years from 1994 to 1998. It will be an important challenge to minimise the between-year variation in yield that has occurred so far, both for leys, cereals and vegetables. A more frequent or properly timed weed control might improve the yields from cereals and vegetables. Both groups of crops would probably have benefitted from a higher supply of plant available N in the spring because the soil and weather conditions have frequently been far from optimal for N-mineralisation.

As regards nitrogen and phosphorus, the nutrient-accounts show an adequate balance after 5 years. It is, however, likely that the net removal of more than 300 kg ha^{-1} of potassium from the systems will have depleted the soil reserves of this element, at least at Landvik. The initial reserves of K in the soil were smaller at this site than at Kvithamar.

By the autumn 1999, the 6-year rotation will be complete, and several soil analyses will be carried out. On the basis of the current soil status and previous recordings and experiences, plans for the continued studies of both systems will be outlined. Important issues will be how to interpret and deal with the potassium deficit and how to improve soil structure in order to optimise the turnover of organic matter and nitrogen. Changes in the crop rotation will also be considered. Some of the presently grown vegetable crops are probably too nitrogen-demanding for a system without its own organic fertiliser-source. Due to the maximum limits to the use of non-organic compost implemented from 1996 onwards, the importance of effective nitrogen fixation in this system will increase.

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An organic vegetable crop rotation aimed at self-sufficiency in nitrogen

K. Thorup-Kristensen
Department of Fruit, Vegetable and Food Science, P.O. Box 102, DK-5792 Aarslev, Denmark

Summary

Nitrogen (N) limitation is a major problem in stockless organic crop rotations, and is thus a hindrance for the development of organic vegetable production. To help develop methods for efficient N husbandry in stock-less organic crop rotations, we are working with a vegetable crop rotation designed to be self-sufficient in N. Although various vegetable crops are grown, 75% of the soil is plant-covered in the late autumn, and in these fields the risk of N leaching losses is kept very low.

During the first few years, all cash crops have shown reasonable yields, and more than half of the cash crops have produced yields on a level we would normally find in similar conventional crops. In the six-year crop rotation, including only one year with a grass clover ley grown as green manure, the cash crops have taken up on average 125 kg N ha^{-1}, and the N removal with harvested products across the whole rotation has been almost 70 kg N ha^{-1} yr^{-1}.

The results show that methods for efficient N husbandry exists which can be used to design stockless organic crop rotations without using a large part of the land for green manures, and with a limited risk of N leaching losses.

Introduction

Nitrogen supply is often a limiting factor in organic crop production. Organic farms with a high stocking rate of cattle, which dominate Danish organic farming at the moment, grow many legumes, and export relatively little N with their produce. Organic farms specializing in other products, especially vegetable production will have problems with the N supply, as their crop rotations include much less legumes, and especially farms which sell many plant products will export larger amounts of N.

We believe that limited nitrogen supply is one of the main factors limiting further development of organic vegetable production in Denmark. From the beginning, vegetable production was an important part of organic production, covering a much higher fraction of the organically farmed area than of the conventionally farmed area. Today approximately 7% of the vegetable area in Denmark is grown organically. This is still a higher fraction than for most other farm products, but during the last five years, the organic vegetable production has increased at a much slower rate than organic farming in general. The fraction of the area that is grown organically is very different for the vegetable crops, from less than 2% for some species to 15% or more for a few species. Half the organic vegetable area in Denmark is grown with carrots, and due to the high productivity of this crop, approximately 65% of the total amount of organic vegetables produced in Denmark are carrots. Carrots have a very small demand for nitrogen supply, and this may be one of the reasons why this crop has been much more successful in organic farming than most other vegetable crops. To increase organic vegetable production, and to increase the number of vegetable crops that are successfully grown in organic farming, better methods of nitrogen supply for the crops should be developed.

Thus we want to test and demonstrate some of the methods which can be used to optimise N husbandry in organic farming within a crop rotation. The results should help organic vegetable farmers to get enough N for their crops and to make them less dependent on external N supply from e.g. cattle farming. The crop rotation should allow the growing of the most common vegetable crops in Denmark. It should thus include years where the N supply is high enough for even the most demanding crops, and other years where the N supply is more moderate, to allow the growing of less N demanding crops without excess supply of N.

In the crop rotation we have attempted to achieve several goals: 1) The crop rotation should be self-sufficient in N. Though this is normally not necessary in practical farming, methods allowing less dependency on import of N from other sources will facilitate the spread of organic vegetable production. 2) The crop rotation should include fewer full year green manure crops than normally used in such crop rotations, and use autumn grown green manure and nitrogen catch crops to optimise N supply for the crops. A full year green manure is thus grown only once during the six-course rotation. 3) The N leaching loss to the environment should be kept low.

In this paper the crop rotation and the ideas behind it will be described. Further, the results in terms of crop yield, soil N supply, crop N uptake, N removal from the crop rotation, and the level of N residues left in the soil in the late autumn.

Materials and methods

The crop rotation is located at the Research Centre Aarslev (10°27'E, 55°18'N), on a Typic Agrudalf soil (Table 1). The crop rotation was initiated in the spring of 1996. Weather data are obtained from a weather station situated less than 500 m from the experimental site.

Table 1 Main characteristics of the soil used for the crop rotation.

	C (%)	N (%)	Clay (%)	Silt (%)	Sand (%)	pH
0-25 cm	2.0	0.15	14.6	27.3	55.2	7.0
25-50 cm	0.8	0.07	19.7	29.8	49.4	6.4
50-75 cm	0.3	0.04	21.7	29.0	48.8	5.1
75-100 cm	0.2	0.03	20.6	28.5	50.6	5.9

The crop rotation consists of six fields of approximately one hectare each. The crop rotation contains:

Field 1: A full year grass clover green manure (including red clover and lucerne). This crop is mown three times during its growth, but no plant material is removed from the field.

Field 2: The field is split to grow both white cabbage and leek. Before white cabbage the grass clover field is ploughed down in late November, but before leek it is ploughed down in late March. Leek and white cabbage are transplanted into the field in May. Two varieties of white cabbages are grown, which are harvested either in September or in November. After harvest the crop residues are left in the field and the cabbage stubble is left growing on as a catch crop. Leek is harvested in November.

Field 3: The residues of white cabbage and leek are ploughed down in March, and in April a barley crop with undersown grass clover is sown. The legume component consists of white clover, black medic and birdsfoot-trefoil. At the harvest of barley the straw is chopped and left on the field. The undersown grass clover is left to grow in the autumn.

Field 4: The grass clover is ploughed down in late March. The field is split, and onions are sown in April and carrots in late May. Onions are harvested in late August and carrots in October. All crop residues are left in the field.

Field 5: The field is ploughed in March, and green peas are sown in April. The green peas are harvested in July, the crop residues left on the soil and ploughed down. As we do not have access to a pea harvester, also the peas are left in the field, but they contain only a small part of the biomass and N in this crop (see Table 2). The crop residues are ploughed down, and around 1 August a catch crop of fodder radish is sown.

Field 6: The fodder radish catch crop dies off during the winter, and in the spring the soil is only harrowed before the sowing of barley with undersown grass clover. The barley is harvested in August, and the straw chopped and left on the field. The grass clover is left to grow in the autumn, and in the next year as a green manure crop (field 1).

Table 2 Yield (fresh weight of saleable products, barley adjusted to 15% water content) dry matter production of whole crop incl. crop residues, total N uptake, and N removal by the crops (Average 1997 and 1998).

		($t\ ha^{-1}$)		($kg\ N\ ha^{-1}$)	
Course and crop		**Yield**	**Biomass, DM**	**N uptake**	**N offtake**
2	Cabbage	69	12.1	173	106
	Leek	31	7.1	151	151
3	Barley after cabbage	4.9	7.7	74	55
	Barley after leek	3.9	6.0	58	49
4	Carrot	100	16.5	68	118
	Onion	42	7.1	127	127
5	Pea	5.3	5.5	116	30
6	Barley after pea	6.8	10.0	113	83

At the harvest of each crop the yield is measured in four subplots. Total yield, saleable yield, dry matter production and uptake of N, P and K in saleable products and crop residues are measured. Soil samples for the determination of nitrate- and ammonium-N is taken in late November as a measure of potential leaching risk after the different crops, and again in May as a measure of the effect of the crops on N supply for the succeeding crops. Soil samples are taken in five soil layers, 0-25, 25-50, 50-75, 75-100 and 100-150 cm.

Soil was sampled from two subplots after each crop, with nine samples combined into one bulk sample for analysis at each soil layer from each subplot. The soil samples were analysed for ammonium-N and nitrate-N after extraction for one hour in a 1 M KCl solution.

Results and discussion

The crop rotation was initiated in 1996 and by now the results from the first three years are available. Yield results from the first year are not related to the effects of green manures and other pre-crop effects, which are so important in the crop rotation. Thus the results presented here are from the second and third year only. These results can be used to evaluate the initial performance of the crop rotation, whether this performance can be kept up on the longer term cannot yet be judged.

The crop rotation

Field 1, Green manure: The full year green manure crop is grown as a mixture of grass, red clover and lucerne, established by undersowing in a barley crop of the previous year (field 6).

Field 2, N demanding vegetables, cabbage and leek: The very N demanding vegetable crops are grown after incorporation of the green manure. The two crops have very different root growth; leek is a shallow rooted crop (Burns, 1980; Smit *et al.*, 1996), whereas white cabbage is deep rooted as many cruciferous crops (Greenwood *et al.*, 1982; Thorup-Kristensen & van den Boogaard, 1998). Thus, before white cabbage we incorporate the green manure in November, whereas before leek it is not incorporated until late March. By spring incorporation it is secured that the available N is present in the uppermost soil layers where it can be reached by the shallow root system of leek. This is not necessary before white cabbage with its deep root system.

After the harvest of these vegetables it is too late to establish a catch crop to prevent N leaching losses. After harvest of white cabbage, we leave the residues of the crop growing in the field as a catch crop. Such a strategy is not possible after leek, but we are testing a system where a catch crop is sown between the leek rows approximately two months after the planting of the leek crop (Thorup-Kristensen, 1997).

Field 3, Barley with undersown grass clover: In the third year a barley crop with undersown grass clover is grown. The N supply for the barley crop is the residual N effect from the vegetables in the previous year and from the green manure grown two years earlier. Thus, the barley crop is not highly supplied with N, and this allows vigorous growth of the undersown grass clover. After harvest the grass clover is allowed to grow as an autumn green manure until the next spring, when it is ploughed down.

Field 4, Less N demanding vegetables, onions and carrots: These two crops demand much less N than cabbage and leek. Carrots have a relatively deep root system, and can utilize the soil N reserves quite efficiently, and produce high yields on a low N supply. Onions demand more N and have a very shallow root system, and can thus only utilize N, which is available in the uppermost soil layers. It has been found that legumes undersown in barley and grown as green manure in the autumn can supply the equivalent of almost 100 kg fertilizer N ha^{-1} (Schröder *et al.*, 1997). Thus, after the autumn grass clover, the growth of the carrots should not be N limited (Greenwood *et al.* 1980; Sørensen, 1993), and onions should only be slightly N limited (Sørensen, 1996). The carrot and onion crops are harvested late (in September and October respectively), and we have no methods for establishing any catch crop to prevent leaching losses of the N left in the soil.

Field 5, Green peas followed by a fodder radish catch crop: After carrots and onions there may be very little available N in the soil, especially if the winter precipitation has been high. Thus we grow green peas, which are not dependent on a soil supply of available N. The green peas are harvested early, and only a small fraction of the crop matter is normally removed from the field (in the experiment none is removed). Thus there are substantial amounts of crop residues to incorporate, and there is time for an efficient catch crop of fodder radish. Fodder radish has a very fast growing and deep root system (Böhm, 1974; Thorup-Kristensen, 1993, 1997). Thus, fodder radish can take up N from deeper soil layers, which have not been reached by the more shallow rooted peas (Thorup-Kristensen, 1998), as well as N mineralized from the soil and from the pea residues after harvest. Previous results have shown that fodder radish is a very efficient catch crop, both in terms of soil N depletion in the autumn, and in terms of N delivery for the subsequent crop (Thorup-Kristensen, 1994).

Field 6, Barley with undersown grass clover: The fodder radish catch crop dies off during the winter, and in the spring a barley crop is sown with an undersown grass clover crop. The undersown grass clover is left to grow during the following year as the full year green manure crop (field 1).

Crop yields

Yield levels of vegetable crops are not easy to compare, as they vary strongly due to many factors. High yield is not always a primary goal, but it is attempted to obtain a specific quality or timing of the harvest even though this may lead to low yields. An attempt to compare the yields obtained in the crop rotation (Table 2) with yields obtained form "similar" vegetable crops grown in conventional experiments at our institute can be made, though even such a comparison can never be precise.

In an experiment with optimal N supply for vegetable crops (Sørensen, 1993), late harvested crops of leek, white cabbage and carrot were grown, which should be comparable to the similar crops in the crop rotation. The carrots in the organic crop rotation produced the same amount of dry matter as optimally fertilised conventional carrots, leek slightly less (7.1 t ha^{-1} vs. 7.5 t ha^{-1}) and white cabbage significantly less (12.1 t ha^{-1} vs. 18.4 t ha^{-1}).

The yield of onions in the crop rotation was somewhat lower than what was found with the same cultivar in a variety test (saleable yield of 41 t ha^{-1} vs. 57 t ha^{-1}, Bjørn (1998)). The yield of the green peas in the crop rotation has been the same as obtained with many of the relevant pea varieties in a variety test with green peas (Grevsen and Kidmose, 1992).

The yield of barley is easier to compare to conventional levels. Barley after peas in field 6 has produced a good yield even by conventional standards, whereas barley after cabbage and especially after leek has produced less than expected from a conventional crop.

Soil N dynamics

An important part of the strategy in the crop rotation is to keep the fields plant covered into the late autumn wherever possible. This is done by growing catch crops or green manure crops in the autumn and after the cabbage crop by leaving the stubble still growing in the field. Where the soil is assumed to be effectively N depleted at harvest, i.e. after the harvest of the two barley crops, an autumn cover including legumes is grown. Where higher amounts of N residues are present at the harvest of the main crop, a non-legume autumn cover is grown which can effectively deplete the soil of its inorganic N content. To summarise the results of this strategy, the fields/crops are split into three groups:

Group 1 where no living crop was present in the field at the time of soil sampling in November, i.e. after leek, onions and carrots

Group 2 where the field was plant covered at the time of soil sampling in November, but the plant cover was killed before the subsequent soil sampling in May.

Group 3 where the field was plant covered at the time of soil sampling in November, and was still covered at the subsequent soil sampling in May, i.e. where grass clover was established in one year and left as a green manure in the following year.

Table 3 Ranges of N_{min} (kg N ha^{-1}) in the 0-100 cm soil layer in November, in May and change from November until May within the three groups of crops (see text).

	N_{min}, kg N ha^{-1}		
	November	**May**	**Change over winter**
Group 1	36 to 149	51 to 91	-61 to 16
Group 2	9 to 26	60 to 138	41 to 114
Group 3	13 to 29	24 to 25	-4 to 13

Comparing the N_{min} measurements in three groups shows very different N dynamics during the winter. In group 1, without plant cover in the late autumn, November N_{min} was quite high, and the N_{min} values were unchanged or reduced before the subsequent soil sampling in May (Table 3). As some mineralisation must have occurred, a considerable loss of N from these fields must have occurred. This is in accordance with the high N_{min} values found even in the subsoil layers in these fields in November at the start of the leaching period (Table 4). In group 2 and 3 the fields were covered in the late autumn, and accordingly November N_{min} was very low, also in the deeper soil layers (Table 4). In group 3 N_{min} was kept low until May, as the grass clover was not ploughed under (Table 5), but in group 2 N_{min} increased strongly from November to May. In these fields an optimal combination of low N_{min} in the autumn before the main leaching period and high N_{min} in the spring before the main period of crop N uptake was achieved. Further, a larger fraction of the available N in May was found in the topsoil layers after group 2 crops than after group 1 crops (Table 5).

Table 4 Ranges of N_{min} (kg N ha^{-1}) in three soil layers in November found within the three groups of crops (see text).

	N_{min} in November, kg N ha^{-1}		
	0-50 cm	**50-100 cm**	**100-150 cm**
Group 1	19 to 58	5 to 100	7 to 32
Group 2	9 to 40	1 to 7	1 to 5
Group 3	9 to 26	2 to 4	2 to 3

Table 5 Amounts and depth distribution of N_{min} in May after three crops from group 1 (onion, carrot and leek) and three crops from group 2 (barley, cabbage and pea). Data from May 1998 only.

	Group 1			Group 2		
	Onion	Carrot	Leek	Barley	Cabbage	Pea
0-150	81	109	70	105	68	91
0-50	31	46	35	88	41	50
50-100	18	27	18	11	19	29
100-150	32	36	17	6	8	12
% in 0-50	38	42	50	84	60	55

N balance

The average N uptake among the harvested crops was approx. 125 kg N ha^{-1}, of which 82 kg N ha^{-1} was removed with the crop at harvest. Across all six fields in the crop rotation this means that there was an N export of almost 70 kg N ha^{-1} yr^{-1}. This amount must be added to the crop rotation by biological N fixation and atmospheric deposition, to make the crop rotation sustainable.

As the pea crop had an N uptake of only 115 kg N ha^{-1}, its N fixation must have been well below 100 kg N ha^{-1}. Eriksen *et al.* (1996) estimated a biological N fixation of 200 to 220 kg N ha^{-1} in ungrazed grass clover pasture. The two fields with an autumn cover of grass clover must be expected to have an N fixation well below that of a full year grass clover pasture. Based on these figures, the average biological N fixation across the six fields is unlikely to reach the 70 kg N ha^{-1} removed with the crops.

As some losses through N leaching, denitrification and ammonia volatilisation must also occur, it seems that the crop rotation could have a substantial N deficit, and the soil should be gradually depleted of its N reserves. On the other hand, large amounts of plant material is added to the soil in the crop rotation, and the soil is plant covered most of the time, thus, significant depletion of the soil organic matter and its N content seems unlikely. The initial results show that the crop rotation has been able to supply the crops with enough N for reasonable yields. Whether the soil N is actually being depleted, maintained or even increased by this crop rotation, can only be answered by future measurements.

Conclusion

Though a precise comparison cannot be made, the results suggest that four of the seven cash crops have produced yields at a level which we would normally expect to find in similar conventional crops, and no crops have shown really low yields. Thus, the crop rotation has for the first few years shown that good yields could be obtained by the methods used, without adding any nitrogen from other sources.

The yearly N removal with the harvested crop parts has been approximately 70 kg N ha^{-1}, and there have been other N losses from the system. To avoid N depletion of the soil, this requires a high N fixation from the legumes in the crop rotation, and a very efficient use of the N, which is fixed. On the other hand, a build up of organic N could be expected due to the extensive crop cover, and the large amounts of plant matter returned to the soil. The results from the coming years will show whether the system is becoming N depleted, the yield level can be maintained, or build up of organic N will occur, and an increased N export is found.

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Crop yields from three organic farm systems at Rugballegaard

F. Oudshoorn[1] *and I.S. Kristensen*[2]
Danish Institute of Agricultural Sciences
[1] *Research Centre Bygholm, Rugballegaard, P.O. Box 536, DK-8700 Horsens*
[2] *Department of Agricultural Systems, P.O. Box 50, DK-8830 Tjele*

Summary

To meet the demands of knowledge on organic pig production and milk production and the demand for better understanding of the factors affecting the nutrient surplus and utilisation at organic farms, three organic systems were set up at Rugballegaard: a dairy system, a pig system and a mixed system with both cows and pigs. The rotations were designed according to the available knowledge on nutrient flow, and the management is constantly kept in touch with the development of guidelines for organic farming in Denmark and EU.

The dairy system allows for a feed import of 10% (based on energy), and a rotation consisting of 60% grass-clover, which should make it possible to maintain 1.1 LU ha^{-1}. The pig system has a feed import of 25% (based on energy), a manure import of 45 kg N ha^{-1}, and a rotation consisting of 20% of grass-clover, which should be able to maintain 0.7 LU ha^{-1}. The mixed system for dairy and pigs allows a feed import of 15% (based on energy) and a rotation consisting of 40% grass-clover, which should be able to maintain 1.0 LU ha^{-1}.

These livestock rates were established in 1996. The livestock rate, the percentage of grass-clover in the rotation and the import of feed will be kept constant until 2000.

For the first two registered years, average dry matter yields of 58 hkg ha^{-1} from the dairy system, 43 hkg ha^{-1} from the pig system and 68 hkg ha^{-1} from the mixed system were obtained. Due to the different agricultural management (the period before establishment) of the areas involved and the heterogeneous soil type of the three large-scale rotation systems, the harvest levels cannot be compared. If an average on cereals only, were calculated, the pig system would be doing surprisingly well, especially when the somewhat poor soil and the low percentage of grass swards in the rotation system are considered.

Introduction

Systematic registrations over eight years in Denmark on a number of organic farms have shown that organic dairy farms and mixed farms had a nitrogen surplus of 124 kg N ha^{-1} yr^{-1}. Arable farms showed a lower surplus of about 83 kg N ha^{-1} yr^{-1}. Although the total nutrient balance especially indicated a surplus of nitrogen, the individual crops often showed clear signs of deficiency. This suggests that there might be ways to increase the efficiency of nutrient use (Kristensen, 1997). The total amount of nutrients entering and leaving the system is relatively easy to measure. However, the nutrient flow through the context of animal digestion and crop production is a different issue. The situation is especially complex because there may be differences between the organic and the conventional systems, and because the nutrient flow in itself will be influenced by the livestock density (LU ha^{-1}) (LU is livestock units). Also, it will be very important to quantify the gaseous losses of nitrogen. This includes losses due to evaporation of nitrogen from the soil, from manure while in the livestock buildings, during storage or during application on the field (Møller & Andersen, 1999). Different feeding components that change the ammonium content in the manure or the design of the building (deep litter or slurry) may also influence the nutrient flow (Kyllingsbæk *et al.*, 1997). All these elements will, of course, be dependent on the system used, but also very much on the climate and the management.

To match the long-term goals, nutrient flows are measured and modelled at the organic research station of Rugballegaard. Unlike the organic pilot farms observed up till now, the three systems established on Rugballegaard are closely supervised by the scientists involved, and they are constantly being developed to match the latest comprehension of nutrient management and flow. The mechanisation of the farms is modern, but not specially designed or atypical. This means that the results obtained at Rugballegaard can be used directly in practice. Also, the scale of the farm systems is comparable to normal size farm systems. Therefore, the energy flow, the use of resources (labour, nutrients) and other agronomic factors can in general be used in the development of organic farming. The objective is not to compare and evaluate the systems, but to understand and develop them.

Materials and methods

In 1996, three crop rotations representing different farming systems were established on an area of 140 ha (Table 1). The area had previously been used for production of roughage for a herd of 200 milking cows. The upper 0-25 cm soil layer is rather heterogeneous. The humus content varies from 3.6 to 6%, and the clay content varies from 5 (coarse sand with clay) to 22% (clay). The average clay content is 11.2% (sandy loam).

Table 1 Characteristics of the three systems at Rugballegaard.

System	Area with grass-clover (%)	Cereals	Feed import[1)] %	Livestock density[2)] (LU ha^{-1})	Manure import (kg N ha^{-1})	Total area (ha)
Dairy	60	40	10	1.1	0	34.9
Pigs	20	80	25	0.7	45	30.9
Dairy/pigs	40	60	15	1.0	0	71.0

1) Feed import calculated as Scandinavian Feed Units (SFU).
2 1 livestock unit (LU) is equivalent to one 550 kg dairy cow or one sow with 20 pigs.

The dairy crop rotation is as follows, with field 5 split into two sub-fields:
1 Spring barley with undersown grass-clover.
2 Grass-clover 1st year
3 Grass-clover 2nd year
4 Grass-clover 3rd year
5.1[*)] Spring oats with undersown rye grass
5.2 Winter wheat

The pig crop rotation is as follows with fields 3 and 4 split into two sub-fields:
1 Spring barley with undersown grass-clover
2 Grass-clover 1st year
3.1 Spring oats with undersown rye grass
3.2 Winter wheat
4.1 Winter wheat
4.2 Spring oats with undersown rye grass
5 Spring barley/peas with undersown rye grass
The mixed dairy/pig crop rotation is as follows with fields 4 and 5 split into two sub-fields:
1 Spring barley/peas with undersown grass-clover
2 Grass-clover 1st year
3 Grass-clover 2nd year
4.1 Spring oats with undersown rye grass
4.2 Winter wheat
5.1 Winter wheat
5.2 Fodder sugar beets

The crop rotation on most organic dairy farms in Denmark has 40-60% of grass-clover. Generally, the farms import 15% of the total SFU (Scandinavian Feed Units) demanded. The animal density is in accordance with the Danish organic guidelines, i.e. max. 1.4 LU ha^{-1} (Kyed & Jensen, 1996).

The slaughter pigs on the organic farm are kept in livestock buildings. The cows graze on grass-clover during the summer for at least 150 days a year, approximately 110 days of which they graze both day and night. The sows are all kept outside in areas with huts (steel plated, insulated). All animals are kept according to the Danish organic rules (Plant Directorate, 1995, 1997, 1999). All spring crops are drilled after ploughing in the spring when the soil is ready. Just before ploughing, the manure (solid or slurry) is applied. The solid manure is ploughed in immediately, whereas for slurry the soil is first harrowed (before 6 hours) and afterwards ploughed. When slurry is applied during the growing season, the soil is harrowed with a tine weeder (Einböck). In the present investigation, all slurry was applied with a 15 t slurry spreader with a spreading width of 12 m and with trailed hoses mounted at intervals of 30 cm. The slurry was sampled for registration of total nitrogen, ammonia nitrogen, K, P and dry matter contents. The amounts applied were registered both by measuring the volume stored in the slurry tank and the weight of the slurry applied. The winter wheat was drilled relatively late, i.e. in the period of 1-20 October. No manuring was done in the autumn. Manuring of the spring sown fodder beets was done in combination with ploughing in the winter.

Mechanical weed control was primarily done by harrowing with a tine weeder (Einböch), and in fodder beets the weed control consisted of hoeing, harrowing and manual hoeing. The amount of grain drilled per m^2 exceeded the normally recommended amount by 20% for fields where large problems with weeds were expected. The drilling was performed at a distance of 24 cm, thereby allowing mechanical hoeing.

The distribution of the slurry and deep-litter manure available was done according to common extension guidelines for organic crop requirements. The grass-clover leys were primarily manured when predestined to silage cutting. Grass-clover fields for grazing were given low priority.

Registration on fields

A systematised registration according to the project "pilot farms" (Kristensen, 1989) was followed at Rugballegaard. The soil was analysed for K, P and Mg contents, and occasionally the N-min content was analysed, as well. The pH was observed, and Mg-$CaCO_3$ was applied, when necessary. All products harvested on the experimental research station were weighed and analysed for contents of N, P, K and dry matter.

All herd fluctuations were noted, including the grazing periods and the location. The amounts of grass-clover consumed by the grazing cows and sows were calculated as a difference between the feeding standard according to growth or the milking yield and the amount of roughage fed simultaneously. By use of the grazing periods and the location, the amount of grass-clover consumed by grazing animals was calculated. All meat and other animal products leaving Rugballegaard were weighed.

Results

For the first two registered years, average dry matter yields of 58 hkg ha^{-1} from the dairy system, 43 hkg ha^{-1} from the pig system and 68 hkg ha^{-1} from the mixed system were obtained (Table 2). Due to the different agricultural management (the period before establishment) of the areas involved and the heterogeneous soil type of the three large-scale rotation systems, the harvest levels cannot be compared.

The average dry matter yield is a sum of the cereals harvested and the roughage harvested and consumed by the grazing herds belonging to the three systems. Due to the fact that pigs do not digest roughage as efficiently as cows and that the amount of dry matter obtained from roughage crops is considerably higher than from cereal crops, the pig system shows low average yields (Table 3). If, however, an average on cereals only, were calculated, the pig system would be doing surprisingly well, especially when the somewhat poor soil and the low percentage of grass swards in the rotation system are considered.

The total amount of nitrogen available for the crops was quite different for the different systems (Table 4). The low livestock rate in the pig system and the low percentage of leguminous plants resulted in an uptake of only 107 kg N ha^{-1}, whereas an uptake of 176 kg N^{-1} ha^{-1} was calculated in the dairy system shows and a content of 134 kg N ha^{-1} was calculated for the mixed system.

The mixed system has a very efficient production, considering the moderate availability of nitrogen and the rather high production of dry matter (Table 2).

The dry matter yields indicate that there is a lower dry matter production in the pig system. If the cereal dry matter yield is isolated, the opposite will be seen (Table 2). Especially in winter wheat yields the pig system will show a relatively high production (Table 3), considering that the system is situated on the sandy areas of the research station.

It seems that the average yield of roughage obtained at the organic research station is higher than the average yield obtained in practise (Table 5). However, the yields obtained at Rugballegaard were only partially net yields (only grazing). The net amount of silage roughage is not yet known. Losses may easily turn out to exceed 25% of the total material.

Table 2 Yields in dry matter (hkg ha^{1}) for the three systems. The straw yield is not included, because some crops are chopped and not weighed.

	Estimated	1997	1998
Dairy system			
Cereals	34	35	35
Roughage	74	86	74
Average	64	56	59
Pig system			
Cereals	31	41 + 0.3[4)]	40
Roughage[1]	42	62[2)]	21
Average	34	49	36
Mixed system			
Cereals	31	43 + 1.5	36
Roughage	74	83	83
Average	54	71[3)]	65

[1)] In the pig system the lactating sows use 40% of the grass-clover for grazing, assuming that there is no net use of grass-clover. Of the remaining 60%, only 40% is used as silage.

[2)] In 1997 the area with grass-clover was twice as large as in 1998, and therefore more grass-clover was used for silage.

[3)] In the first year of the rotation system an additional 7 ha extra of grass-clover was included.

[4)] Only some of the spring cereals with undersown grass-clover are used for grazing or cutting after the harvest, depending on the need of fodder. The grass-clover and the rye grass are cut short before the winter. The material is left on the field as green manure.

Table 3 Yields in dry matter (hkg ha^{-1}) by crop.

	Estimated	1997	1998
Dairy system			
Spring cereals	34	35	33
Winter cereals	43		41
Grass-clover	78	86	74
Pig system			
Spring cereals	30	44 + 3[1]	41
Winter cereals	34	53	49
Grass-clover	34	62	21
Mixed system			
Spring cereals	30	44 + 3	41
Winter cereals	36	39	43
Grass-clover	78	82	84
Fodder sugar beets	106	114	115
Wholecrop cereals	52	72 + 2	63

[1)] Grazed after harvest

Table 4 Calculated annual nitrogen application (Kristensen & Kristensen, 1997) (kg N ha^{-1}).

	Dairy	Pigs	Mixed
Net excretion by grazing animals	38	30	42
Applied manure	88	98*	67
Estimated available manure N to crop	49	47	32
Estimated fixation by clover and peas	89	30	60
Total	176	107	134

* Including imported 45 kg N ha^{-1}

Table 5 Cereal and roughage net yields (used for fodder or sold) at organic dairy pilot-farms 1989-92 (Kristensen, 1997).

Crop	Net yield (hkg DM ha^{-1})
Spring barley	28 + 4
Winter wheat	42
Grass-clover	75
Fodder beets	105
Whole crop cereals	49+6

Discussion

It is always difficult to use the results of dry matter yields from a research system as an indication of the yield level in general. But if one should want to find a level for use in modelling or extrapolation, the full-scale farm results obtained from a well-defined rotation system (with all its natural variations of management, climate, variation in soil type within fields, previous management and rotation) will be a qualified method to use.

Considering that the systems have only been used in practise for three years (including the conversion period that will normally give a temporary yield suppression when no grass-clover or manuring has been used in the previous crop rotations), the yield level obtained has proven to be higher than calculated. One explanation could be that the available amount of nutrients was higher than that calculated. Another explanation could be that the fixation was higher than modelled. A third possibility is that the weed control was better than the results from the pilot farms, where the modelling calculations had been used.

The cereal production in the pig system was surprisingly high. The calculated amounts of available nitrogen were obviously too low, because the ammonium percentage of the total nitrogen in slurry and manure was higher than in the dairy systems. This also explains the positive effect on winter wheat, where good spring development is prerequisite for high yields in organic systems.

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Partner farms: a participatory approach to collaboration between specialised organic farms

W.J. Nauta, G.J. v/d Burgt and T. Baars
Louis Bolk Institute, Department for Research and Extension in Organic Farming
Hoofdstraat 24, NL-3972 LA Driebergen

Summary

In the Netherlands, specialisation has all but wiped out mixed farming systems; in the organic sector, too. Mixed farming is the preferred system in organic agriculture, but turning back the clock is not a feasible option; besides, specialisation does have advantages. Partner farms, collaborations between arable and dairy farms, may combine the best of both worlds.

The Partner Farm concept is being worked out in practice in the project "Development and demonstration of Partner Farms", with 5 dairy farms (260 ha grassland in mainly peatland areas) and 4 arable farms (130 ha on clayey soil). The first priority is to develop a fair exchange of (high energy and protein) feed and straw for farmyard manure.

The main difficulties at this time are the lack of a product valuation system and the adjustments, which individual farms must make to fit in the "mixed" situation; for example reducing manure applications, increasing frequency of cereal crops, growing high energy fodder crops, and sharing labour and knowledge. For the collaboration to succeed, farmers in the project must start thinking along "mixed" lines and thus attribute realistic user values to their products.

Introduction

Mixed farming is the preferred system in organic agriculture for several reasons. Firstly, a mixed production cycle better retains nutrients (N, P, K) and organic matter. Secondly, nutrient uptake is more efficient, reducing the need for external inputs such as concentrates, chemical fertilisers and biocides. Finally, the manpower available on a farm is employed more effectively in mixed farming systems (Bos, 1998). The result is a more sustainable production system that is less dependent on external circumstances.

In many developed countries, however, agricultural production has become highly specialised in response to market forces and technological developments. This applies equally to organic and conventional agriculture (Baars, 1998). Specialisation is also determined by local conditions (soil type, water table), which may be more suitable for one type of production. Dairy farming is predominant in regions with peat soils, sandy soils and heavy clay soils, which are really only suitable for pasturage. Lighter clay soils and loamy soil, on the other hand, are easier to work and are therefore ideal for arable production. Specialisation, however, has its price. High-energy (concentrate) feed may be in low supply on dairy farms depending on the ratio of clover to grass in the sward, so that farmers must buy concentrates. And arable or horticultural farms have no choice but to buy farmyard manure and include cereals and cover crops in their crop rotation to maintain soil fertility.

We cannot simply turn back the clock on specialised farms. Besides, specialised production has its advantages, too. Farmers today must participate in quality assurance systems and satisfy environmental regulations, and this requires a high level of specific expertise. The Partner Farm concept is aimed at establishing intensive collaborations between specialised farms, so that they may reap the benefits of a mixed system while retaining their autonomy (Baars, 1998). The concept is being developed in practice with nine highly specialised farms. Intensive consultation on our part is necessary to achieve the desired degree of synergy between the farms for a truly "mixed" situation.

Materials and method

Partner farms

The partner farm concept is implemented in the project "Development and demonstration of partner farms" in the province of Noord-Holland. The project comprises five dairy farms with a total of 260 ha of grassland and 1.7×10^6 kg milk and four arable farms with a total of 130 ha. A general outline of the farm systems is depicted in Table 1. The dairy farms participating in the project do not really have suitable soil for growing fodder crops or improving the sward (peat soils and clay on peat), while the four arable farms have ideal soil for all sorts of crops. The distance between the dairy and arable farms is at maximum 35 km.

Table 1 Outline of the nine farm systems in the partner farm project in hectares.

	Dairy					Arable				Total
	1	2	3	4	5	6	7	8	9	
Area (ha)	52	17.5	37	38.5	115	36	21	29	43	389
Soil	clay	clay	clay/ peat	peat	peat	clay	clay	clay	clay	
Perm. grassland	-	10.5	22	31.5	63	-	-	-	-	127
Grass-clover	40	4	-	7	10	-	3.5	-	-	64.5
Nature land*	12	-	15	2	42	-	-	-	-	71
Wheat	-	2	-	-	-	12	7	9-11	14.3	43.3
Alfalfa	-	-	-	-	-	12	0	5.8	14.3	42.1
Market crops	-	-	-	-	-	24	17.5	23.2	28.7	93.4
Fodder beet		1								1
Tulips	-	-	-	-	-	6	1.8	0	0	7.8
Cover crops	-	-	-	-	-	18	0	14.5	21.5	54

*Nature land is leased from the Government and the grass cannot be harvested before 15 June.

Participatory approach

The aim of the project is to achieve a sustainable collaboration between the farms such that they form a "multi-location mixed system". Incorporating the mixed farm principle in daily farming practice will require major changes to farm management on each farm. The farmers will have to learn to "think mixed", such that they automatically consider the other specialisation when making their annual management plans. To this end, researchers from Louis Bolk Institute provide consultation and extension according to participatory principles (Baars & de Vries, 1998, 1999). This includes group extension sessions during which farmers compare their farm situations and learn to see the different perspectives of arable and dairy production. Computer models such as FARM and NDICEA (Oomen & Habets, 1998) extrapolate data to predict future situations. In addition, the project team proposes and initiates changes and product exchanges. Financial support is available to farmers during the first three years of the project to compensate for any risks or additional costs resulting from the collaboration.

FARM

FARM, developed by Oomen & Habets (1998) is a static computer model developed especially for mixed organic farms. Specialised farms, too, can be entered into the model. Input data includes, general farm data, livestock data, crop data, and information on means of production such as buildings, machines, labour and financial reserves. The programme produces an overview of a farm's feed balance, N-P-K nutrient balance, organic matter content, financial situation, and division of labour. This information can be used to assess farm management on its own or as part of a possible partner farm combination.

NDICEA

The computer model NDICEA, Nitrogen Dynamics in Crop Rotations in Ecological Agriculture, is a dynamic model to predict the course of N in soil. The current version (Oomen & Habets, 1998) integrates three models for the mineralisation of organic matter, water supply (i.e. nitrogen input) and crop growth (i.e. water and nitrogen uptake). The model requires data on the environment (precipitation, temperature, evaporation rate), the soil (type, water table), crops (growth curve, yield, N content, crop remains, cover crops), fertilisation (when, how much, source, contents of N and organic matter) and cultivation (general pattern of all activities).

Results

Farm analyses

There are many differences between the nine farms. The dairy farms, for example, range from a small farm on clayey soil with twenty cows in a traditional tied-up barn to a farm on peat soil with 120 dairy cows, cubicle housing and an automated milking system. The arable farms, too, vary from fairly traditional requiring only part-time labour to highly enterprising farms, processing their own produce and selling them around the world. The arable farms are all situated on either heavy or light clay soil.

The dairy farms have been thoroughly analysed. A fodder specialist has analysed the farms' feed balance. Farm structure, grassland management and grassland quality have also been assessed. The first priority for these farms was to realise improvements in farm management and to optimise the utilisation of inputs. Our analyses of the dairy farms focused on fodder production and fodder intake, but also extended to related matters such as fertiliser regime, milk production, and nutrients and organic matter contents in soil. We found that all the dairy farms had structural roughage surpluses and deficits in energy-rich feed and protein, which could be alleviated by increasing clover content in the sward. In addition, we found that they would benefit from reducing their applications of farmyard manure, as grassland is capable of maintaining high organic matter and potassium levels and of supplying its own nitrogen, provided there is sufficient clover in the sward. Applications of natural phosphate fertiliser would help prevent phosphate deficiency. This more efficient fertiliser regime has the added advantage of leaving more farmyard manure for arable farms.

The arable farms in the project buy all their farmyard manure and with regulations for organic production allowing the use of conventional manure, much of it originates from conventional farms for bargain prices. Our other analyses of the four arable farms concentrated on current crop rotation schemes. The farmers recognise the importance of soil fertility and this is reflected in their crop rotation schemes, which include biennial alfalfa or a grass-red clover mixture. The total area under wheat has declined in recent years in favour of field vegetables which bring a better price on the market, but which are more taxing for the soil. Cover crops such as clover and alfalfa fix nitrogen and can reduce a farm's dependency on farmyard manure. They also help reduce weeds (grass-clover and alfalfa) and improve soil structure (wheat and alfalfa).

The cover crops which arable farmers grow to maintain soil fertility (alfalfa, grass-clover) could be sold to dairy farmers as high-quality organic fodder. This would greatly enhance the crop's value and ensure its place in crop rotation schemes in the future. However, this all depends strongly on whether farmers think the price is right.

Product exchanges

One of the first steps towards collaboration was to set up a system of input exchanges, i.e. manure, straw and fodder. The results presented here apply to the nine farms in the project and two demonstration farms. The specific problems posed by partner farming have been discussed at length during extension sessions with the participating farmers. The farmers requested special attention to the valuation of the various products to be exchanged. Clearly, products produced in a mixed organic system have more than just an economic value, and the farmers would like to know more about alternative methods of product valuation and assessment.

Table 2 Production* and use** of farmyard manure (FYM), straw, wheat and alfalfa in the partner farm project (tonnes per year).

	Dairy farms	Arable farms	Surplus/deficit	Supply as % of demand
FYM	2100*	1953**	+147	108
Straw	320**	162*	-158	50
Wheat	150**	243*	+93	162
Alfalfa	150**	580*	430	386

Manure

Table 2 shows the total production of and demand for manure, straw, wheat and alfalfa. In theory, the five dairy farms produce enough manure to cover the arable farms' requirement. However, at the beginning of the project, dairy farmers were only selling 240 tonnes of manure a year. Our own experience in farm consultation is that reducing manure applications on grassland is beneficial to grass production. This is backed up by scientific literature (Baars and Younie, 1998). Dairy farmers in the project were therefore encouraged to use less and sell more manure, so that 500 t yr^{-1} is now available for the arable farmers. The arable farmers in turn have agreed to buy this volume of manure, although they may require financial compensation to cover the price difference between organic manure and conventional manure.

Straw and wheat

The farms in the project can supply 50% of the demand for straw. However, of the 162 tonnes produced, only 54 tonnes is currently sold within the Partner Farm project; the remaining quantity is kept by farmers for their own use, for example in the culture of bulbs. Most of the wheat is winter wheat of bread-making or brewery quality. The relatively high cash value of these crops makes them unsuitable for fodder.

Legumes: alfalfa and clover

Alfalfa is abundantly available. By coincidence, a drying plant is situated in the vicinity of the arable farms, so that growing alfalfa is quite lucrative for these farmers. The suitability of alfalfa as an ingredient in organic concentrate (in addition to wheat) is being studied. In the winter of 1998-1999, 35 tonnes of alfalfa-wheat concentrate (a 50-50 mix) were produced and experimentally used on the five dairy farms. The alfalfa is currently grown as horse fodder, with a maximum dry matter content, and harvested three times a year when it is not yet in full flower. When harvested at this stage, the energy content of alfalfa is low: 781 VEM per kg dry matter (1 VEM = 6,9 MJ). Thanks to the addition of wheat, our alfalfa-wheat concentrate contained 847 VEM kg^{-1}. As conventional concentrates contain 960 VEM kg^{-1}, this caused a slight drop in milk yield per cow (0.3 kg day^{-1}) as well as a slightly lower percentage of milk fat (on average, 0.2% less). We had, however, expected lower yields.

Another batch of alfalfa-wheat concentrate was made in the spring of 1999. The alfalfa was now harvested at a younger stage, following the recommendations of Van der Schans (1998) (maximum length 50 cm and no more than 50% green buds). We expect that this will result in a feed value of 820-850 VEM kg^{-1} for alfalfa alone. The VEM value of alfalfa is however underestimated when it is measured as for grass. Crude fibre in alfalfa does not contain lignine and therefore the VEM-value is approximately 70 VEM too low. With this taken in account, we expect at least 920 VEM in one kilogram alfalfa-wheat concentrate.

Baars (1998) stated that the key to successful partner farming is an optimal use of clover on both dairy and arable farms. Clover reduces the need for nitrogen inputs in both systems, so that product exchanges can be directed at satisfying other mineral and organic matter requirements (Ca, P, K and Mg). On dairy farms, a higher clover content in the sward would reduce the need for protein inputs; i.e. concentrates, thus increasing farm income. Currently, the dairy farms in the project have too little clover in the sward. On peat soils with a pH of about 5, however, maintaining clover is a real challenge. These farms will always be dependent on manure and peat mineralisation for nitrogen, and will also continue to be dependent on arable farms to cover a part of their protein need.

Example of a partnership between two farms (Dairy 1 and Arable 6)

On the basis of the available data, we have split the dairy and arable farms in the project into groups of two to further elaborate the Partner Farm concept. The first two farms to qualify for this more intensive form of collaboration are Dairy 1 and Arable 6. These two farms have already implemented many improvements in organic farm management and have realised an exchange of manure for straw.

Dairy 1 has a milk quota of 336 t. The farm houses 60 dairy cows, which consume 50 t of bought concentrates (960 VEM + 90 DVE kg^{-1}) per year. The animals are housed in a shed with sloping floors ("hill barn"). This housing system requires 12 kg of straw per cow per day, or 190 t of straw per year. 750 t of farmyard manure are produced per year, of which 100 t is sold to Arable 6. Ultimately, Dairy 1 should sell two-thirds of its farmyard manure in exchange for more straw, which means that Arable 6 will have to expand the area under wheat.

Arable 6 has 36 ha of arable land with 10 ha alfalfa each year, producing an average yield of 15 t ha^{-1}. The area under wheat is 5 ha, yield 5.5 t ha^{-1}. These crops are the primary ingredients of alfalfa-wheat concentrate. If Arable 6 grows less alfalfa, but harvests it earlier to ensure a higher feed value, and increases the area under wheat, its production would tie in with Dairy 1's input needs, i.e. more straw and concentrate with a high feed value. About 25 t of fodder wheat, requiring 5 ha, would be sufficient. The winter wheat, which is harvested in August, could be followed by alfalfa, which in turn could be harvested at an early stage the next year.

These proposed changes have been analysed with FARM for the two farms working as one unit (Partner farm). The results, that are nutrient inputs and outputs and efficiency, are shown in Table 3. We also present the current situation on each of the farms separately and the current sum situation, that is a weighted average of the two farms together, as measures for comparison.

Dairy 1 currently buys 45 kg N ha^{-1} in concentrates, whole plant silage and straw, and outputs 11 kg N ha^{-1} through the sale of 100 t of farmyard manure. 38 kg N ha^{-1} is sold as milk and meat, so that the farm's N efficiency-1, based on purchased inputs and sold outputs (Baars, 1991; Watson & Atkinson, 1999), is (38+11)/45)*100=109%. Including fixation and deposition, this value drops to 31% (efficiency-2). Arable 6 achieves an N efficiency-1 of 244% and the efficiency-2 is 80%.

In the Partner Farm, Dairy 1 and Arable 6 optimally dovetailed their farm management. We assume that such a Partner Farm would be self-sufficient in concentrates and whole plant silage as well as farmyard manure. These products would therefore no longer need to be bought. A supplementary purchase of 161 tonnes of straw would still be required for the housing of the animals. In this scenario, the total purchased input of N into the system would be only 11 kg ha^{-1} in straw, while 74 kg N ha^{-1} would be outputted in meat, milk, food and fodder. N efficiency-1 would then reach the extreme value of 673% due to 93 kg N ha^{-1} from fixation and deposition.

In comparison, we have presented the sum situation of Dairy 1 and Arable 6 using weighted averages per hectare. This sum situation is based on the farms' current independent style of management. Comparing the Partner Farm situation with the sum situation shows that Partner Farming would be an impressive win-win situation for both partners in the case of nitrogen. Efficiency-2 would be 71%, or 6% more than in the Dairy 1 + Arable 6 sum situation. The net loss of nitrogen declines from 60 to 30 kg ha^{-1} in favour of the Partner Farm.

This does not apply to phosphate. The phosphate balance is negative in all scenarios. In the Partner Farm scenario, applications of natural phosphate fertiliser would be required. As for potassium, in the Partner Farm scenario a supplementary application of 42 kg K ha^{-1}, for example vinasse, would still be required after trading off the surplus on Dairy 1 against the deficit on Arable 6. The dry organic matter balances for Dairy 1, Arable 6 and Partner Farm are 1577, 385 and 3161 kg ha^{-1} yr^{-1}, respectively. Thus here, Partner Farming would again benefit both partners.

Table 3 Nutrient inputs and outputs on Dairy 1 and Arable 6, Dairy 1 and Arable 6 together, and Dairy 1 and Arable 6 working as a partner farm, calculated using the computer simulation model FARM. Efficiency rates express how much of the purchased (efficiency-1) and total (efficiency-2) N, P and K inputs become available as sold output.

	Dairy 1 (52 ha)			**Arable 6 (36 ha)**			**Dairy1+Arable6 (88 ha)**			**Partner farm (88 ha)**		
(kg ha^{-1})	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Purchased inputs												
manure				80	21	199	33	9	81			
organic fertiliser						36					10	42
concentrates	19	2	2				11	1	1			
fodder (roughage)	4	1	4				2	1	2			
straw	22	4	37				13	2	22	11	2	18
Subtotal:	45	7	43	80	21	235	59	13	106	11	12	60
Atmosphere input												
fixation	80			130			76			58		
deposition	35			35			35			35		
Total (1)	160	7	43	245	21	235	170	13	106	104	12	60
Sold outputs:												
food (for people)				56	11	73	23	5	30	22	4	31
fodder				129	14	91	53	6	37	25	2	17
meat	3	1	0				2	1		2	1	
milk	35	6	10				21	4	6	21	4	6
manure	11	3	6				7	2	4			
other				10	2	14	4	1	6	4	1	6
Total (2)	49	10	16	195	27	178	110	19	83	74	12	60
Net loss (1-2)	111	-3	27	50	-6	57	60	-6	23	30	0	0
Efficiency 1(%)	109	143	37	244	128	76	186	146	78	673		
Efficiency 2(%)	31	143	37	80	128	76	65	146	78	71	100	100

Discussion

The advantages of mixed farming systems for both conventional and organic production have been described in detail in the literature (van Keulen *et al.*, 1998). There are different ways of achieving a mixed system, however. In this project, we wish to respect the autonomy of specialised farms, but encourage them to mimic a mixed system through intensive collaboration (Partner Farm concept). This innovative approach is well suited for the Netherlands where arable and dairy farms are often within close range, and where soil type and a tradition of specialisation often do not allow a conversion to mixed farming. The project described here is still ongoing; the presented results are provisional and our only aim at present is to give an idea of what we hope to achieve with the project.

Trying to achieve a collaboration between farms unearths several practical problems: what valuation method could be used to give exchanged products a value that expresses more than just their economic worth; how can farmers acquire new knowledge of specific management measures as well as of each other's production system; how can the economic interests of individual farms be simultaneously addressed; how should transportation costs be settled, and so on? These problems can be solved through a process of learning and raising awareness (Baars & De Vries, 1998; Drummond, 1998). They cannot be solved on paper; it is necessary to actually confront participants with the problems as they arise in practice, so that they can feel which changes are necessary and are forced to think about their farm in a more holistic context. Ultimately, they must learn to think from the perspective of a mixed system.

In the early stages of the Partner Farm project, we have been careful to take small steps, which do not require sweeping changes in the farms' production systems. Thus, farmers readily agreed to the production of concentrates because alfalfa was already being grown in ample quantities on the arable farms and because dairy farmers did not have to change their feed system. Later, we realised that additional changes had to be made: the quality of the alfalfa had to be improved, arable farmers had to adjust their crop management to meet dairy farmers' needs and arable farmers were asked to consider growing fodder wheat as well. This last point, however, has proven difficult, as the soil is particularly suited for growing bread wheat, which brings a better price on the market. Trading in some of the area under alfalfa for a greater area under wheat does not change this hard fact. Currently, therefore, fodder wheat for alfalfa-wheat concentrate is being bought from farms elsewhere in the Netherlands. The only reason for arable farmers in the project to switch to growing fodder wheat is an idealistic one, and it would only be reasonable to expect them to act idealistically if it was economically possible.

More wheat production in the system also means more straw. However, the stable with sloping floors in the project requires more straw (8 kg $cow^{-1}day^{-1}$) than could ever be produced within the partner farm system. Supplementary straw will always have to be bought from elsewhere. In view of this, we wonder about the feasibility of deep litter housing in the Netherlands, where wheat is a relatively minor crop.

In an optimal mixed system, nitrogen fixation by legumes is required in both parts of the system (Baars, 1998). The three dairy farms on peat soil in our project, however, have great difficulties maintaining clover in the sward (low pH, mineralisation of nitrogen and slug problems). This soil is also unsuitable for the production of whole crop silage from wheat, so that these farms will always be dependent on arable farms for high-energy whole plant silage, nitrogen and protein from concentrates. Therefore, in a Partner Farm situation, the limitations of this soil type will always cause higher nitrogen losses for the total system.

Another interesting question raised in this project concerns the optimal ratio of arable land to grassland. The ratio is 260:130 or 2:1 for all nine farms participating in the project. Livestock density plays an important role in determining which ratio is optimal. The dairy farms in this project have an average livestock density of 1.3 Livestock Units (LU) per hectare (low by Dutch standards); or 0.87 LU ha^{-1} when the total land area of all nine farms is considered. This is well within the optimal range of livestock density on organic mixed farms, which has been shown to be between 0.8 and 1.0 LU ha^{-1}.

However, considering that the sum situation of the nine farms is a roughage surplus and a manure deficit, there is still scope to increase livestock density.

The Partner Farm scenario, where Dairy 1 and Arable 6 function as one mixed system, depicts an idealised situation. We only use this scenario as a guideline in the Partner Farm project. As yet our scenarios are limited to nutrient inputs and outputs, but we feel that this gives a good indication of how open or closed a system (potentially) is. The idealised Partner Farm situation would get considerable benefits to the two farms with respect to nitrogen losses. However, the scenario only shows that the Partner Farm could be self-sufficient in manure; the model does not show where the manure would be applied. In practice, the dairy part of the Partner Farm would insist on keeping some farmyard manure to maintain the soil fertility and soil life of its grassland. A field study is planned to determine exactly how much manure the dairy farm would require.

The production of alfalfa-wheat concentrate within the Partner Farm would significantly reduce the required N input, but it should be kept in mind that reducing the area under alfalfa would also reduce the total fixed nitrogen. Total N losses in the Partner Farm scenario would be half that of the current sum situation of the two farms. However, a total N loss of only 30 kg ha^{-1} may not prove feasible in practice. Due to the inefficient distribution and delayed availability of fixed nitrogen, optimal crop production can only be achieved with a moderate surplus of nitrogen.

Dairy 1 has an excellent distribution of clover in the sward. On Arable 6, however, nitrogen is only fixed on 10 hectares under alfalfa. The alfalfa is sold and leaves the farm after harvesting, so that only root derived nitrogen remains on the farm. We examined this cycle more closely with NDCEA. The model shows that the remaining nitrogen produced by alfalfa is only 100 kg N ha^{-1}, i.e. 1000/36=28 kg ha^{-1} for the whole farm. This nitrogen becomes available for crops grown in the following years through a gradual process of mineralisation. We hope to increase the efficiency of the cycle by seeking an optimal growing time for alfalfa, timing the harvest when nitrogen fixation by the plant roots has passed its peak. We will also study whether fodder wheat could precede alfalfa without reducing nitrogen fixation.

Nitrogen fixed by alfalfa might also be better distributed and used if the alfalfa is composted or if the last second-year cut is ploughed under. The volume of nitrogen leaving the farm would be greatly reduced and N losses on the farm in the Partner Farm scenario would increase to 55 kg ha^{-1}.

Conclusion

The Partner Farm project has not yet been concluded. The project is a matter of learning, experimenting and adjusting and re-adjusting to the many new opportunities and processes. In this article, we have tried to describe the main issues currently being tackled in the project. Over the next few years, we will continue to develop and fine-tune the Partner Farm concept.

The only conclusion that we can make at this stage in the project is that the Partner Farm concept has considerable potential as a method of increasing the sustainability of organic agriculture in certain regions in the Netherlands. Partner Farming may stimulate the further development of the organic sector, provided the reliance on low-priced conventional products such as manure and concentrates can be reduced. We expect that new legislation now being developed to restrict the use of conventional inputs will pave the way for a new valuation of organic inputs and thus for the integration of organic arable farming and organic dairy farming in the Netherlands.

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Crop rotations on organic farms in Northern Germany and development of the wide row system

R. Holle and H. Untiedt
Ökoring Schleswig-Holstein, Kielerstrasse 26, 24582 Bordesholm, Germany

Summary

The usual crop rotation in Northern Germany includes 25% to 33% grass-clover. Because there is not enough nitrogen for all the cereals in these rotations it is of the utmost importance to grow undersown legume crops to increase nitrogen fixation. But for grass-clover grown in the customary manner there always is a problem of little exposure to light and because of this it tends to be of inferior quality and size. On the other side, in case of successful grass-clover cultivation the following wheat often has too low a content of crude protein. An interesting solution to the complex problems associated with this dilemma has been the use of wide row spacings, hence called the wide row system. The development of this system led to a considerable strengthening of the clover grass. Furthermore it allows for relatively high levels of grain biomass and protein yields, which for wheat is of fundamental value. As far as the farms of our investigation are concerned the row spacing varied from 0.3 to 0.5 m. For organic farmers the wide row system seems to be a promising way of producing wheat with a protein quality, which meets the needs of the market.

Introduction

The usual crop rotation in Northern Germany includes 25% to 33% grass-clover. The common rotations use 25% grass-clover undersown in the cereals, because this gives a higher yield over the whole rotation. In normal rotations the following problems often occur:

- On heavy soils with enough water there are high yields of wheat, but the quality of protein is reduced.
- The cereals furthest away from the grass-clover may not have a sufficient nitrogen supply, because the undersown legume does not supply nitrogen to the crop.
- If the farmer tries to grow undersown legumes very frequently, there will be less stubble breaking and as a result perennial weeds like thistle and couch grass becomes prevalent.

  A method of growing grain and grass-clover permanently is originated by the organic farmer Joachim Stute and is now commonly known as the wide row system. The wide row system allows cereals and grass-clover to be intercropped, increasing the protein-content of the wheat to a higher level. Wheat with a crude protein below 10.5% can only be marketed for feed. If the crude protein is above 10.5% it can be sold as baking wheat.

The procedure of the wide row includes:

- Drilling of the grains in single rows, seldomly in double rows.
- Amount of seeding 33% lower than the standard seeding rates.
- Width of row spacing about 0.3 to 0.5 m.
- Several repeated hoeings until heading (EC 49).

- Drilling of underseeds after the last hoeing.
  Because the price difference of feeding wheat and baking wheat is approximately 10 EURO per 100 kg, the organic farmers are interested in producing wheat with a higher crude protein content. The evaluation of wheat analyses from organic farmers of the last years demonstrates that only half of the wheat samples were of baking wheat quality, although wheat was grown mostly in the year following grass-clover.

Materials and methods

The wheat fields of 33 organic farms, members of product organisations BIOLAND, NATURLAND or DEMETER, were assessed during the harvest of 1997. The exact yield, the protein content and water content of their harvests were recorded and samples of crude protein and gluten were taken. The test areas were spread over the three geologically different regions of Schleswig-Holstein (Table 1). Items important for assessing the production methods were ascertained by a survey.

On the farm "Brock" at the east coast several cultivation methods were tested. The spring-wheat variety "Combi" was used. The cultivation methods included:
For standard seeding (0.125 m row spacing):

- without maintenance works
- with use of curry-comb

For the wide row system (double row, 0.375 m row distance)

- with use of hoe
- with use of field cultivator

Table 1 Distribution of the farms and fields in the regions of Schleswig-Holstein .

Region	Numbers of farms	Numbers of fields
East coast	20	53
Fehmarn	5	17
West coast	8	21
Sum	33	91

Results and discussion

Table 2 shows the results of the yield and quality ratings of wheat from farms in different areas of Northern Germany. These values show a very high variation and therefore exact interpretation requires division in three categories depending on site, variety an production method:

1. "region" (East coast, Fehmarn, West coast)
2. "variety" (spring-wheat, winter-wheat)
3. "production method" (wide row, normal seeding)

Table 2 Overview of mean and minimum and maximum values and standard deviation of the key variables yield, crude protein, gluten and N-uptake. Numbers of samples: 91.

	Yield (t ha^{-1})	Crude protein (%)	Gluten (%)	N-uptake (kg N ha^{-1})
Mean	4.0	11.3	22.3	69
Minimum	2.2	9.7	14.1	36
Maximum	5.9	14.2	30.8	109
Standard deviation	8.5	1.3	3.7	17

This differentiation of the data according to the categories defined above allows conclutions to be drawn more easily, as can be seen from Table 3. The regions of Fehmarn and the West coast seem to be privileged places for a high yield with high values of gluten and crude protein. The category "variety" shows that spring wheat gives lower yield, but a higher quality than winter wheat. The quality effect of the wide row system may be seen from a content of crude protein of 11.7% and of gluten of 24.0% on average. Since the production method of the wide row system is more widely used at the West coast this leads to the complication that the quality effects of this system indicated by Table 3 may in part result from the different soils. But Table 4 shows comparison of the wide row and standard seeding in one region only. The yield of the wide row system is less but the crude protein is higher than of the standard seeding.

Table 3 Mean values of the variables yield, crude protein, gluten and N-extraction by the different categories. Values above the mean of the whole sample (see above table 1) are printed in bold.

Category	Yield (t ha^{-1})	Crude protein (%)	Gluten (%)	N-uptake (kg N ha-1)
Region				
East coast (n=53)	3.9	11.1	22.0	66
Fehmarn (n= 17)	4.2	10.9	22.6	71
West coast (n=21)	4.2	11.9	23.1	78
Variety				
S.-wheat (n=37)	3.9	11.9	23.4	71
W.-wheat (n=54)	4.1	10.9	21.3	69
Production method				
Wide row (n=44)	3.9	11.7	24.0	71
Normal seeding (n=47)	4.1	10.9	21.3	68

Table 4 Comparison of the quality effect of the wide row of the East coast region depending on the production method.

Production method	Yield ($t\ ha^{-1}$)	Crude protein (%)	Gluten (%)	N-uptake (kg N/ha)
Standard seeding	4.2	10.8	20.9	70
Wide row	3.8	11.7	23.6	62

Table 5 Results of the wide row experiment on the farm "Brock".

Variety	Yield ($t\ ha^{-1}$)	Crude protein (%)	Gluten (%)	N-uptake (kg N/ha)
Normal seeding (no maintenance)	2.3	10.4	19.4	37
Normal seeding (curry-comb)	3.2	10.8	20.5	54
Wide row (field cultivator)	3.3	12.0	24.8	61
Wide row (hoeing)	3.0	12.9	26.3	60

On average the difference between common seeding and the wide row system is about 0.2 $t\ ha^{-1}$. For the East coast region the difference is 0.35 $t\ ha^{-1}$. These differences were, however, not significant.

The effect on quality of crude protein and gluten is confirmed by the experiment on the farm "Brock" at the east coast (Table 5). The normal seeding with a yield of 2,3 $t\ ha^{-1}$ seems to be to low. The reason was most probably presence of the cornflower weed. The use of curry-comb had no measurable effect to the quality of crude protein, whereas the wide row system resulted in a very high crude protein and gluten. The N-uptake ($kg\ ha^{-1}$) is considerable, too. With the use of the field cultivator or the hoe more nitrogen is mobilised.

39 of 44 grain samples (89%) analysed from the wide row system had a crude protein above 10.5%. Only five samples had less than 10.5% crude protein, an explanation for this may be their origin with heavy soils and high output and nitrogen being thinned out. For locations like these a greater width of row spacing (about 0.5 m) may prove sufficient to guarantee a high crude protein in the future.

The use of spring or winter wheat is also important for the effect on quality. Only 55% of winter wheat, but 95% of spring-wheat had more than 10.5% crude protein.

Acknowledgement

The project "Monitoring the wide row with regard to quality of organic-baking wheat" was kindly supported by the Department of Agricultre in Schleswig-Holstein, Germany, 1997. Part of this project´s findings are integrated in the following paper.

This investigation of the 1997 yield monitoring has been supported by the investigations of Jochen Hochmann, LWK Schleswig-Holstein, Futterkamp 1996-98.

Nitrogen cycling and crop production

Influence of 2-, 3-, 4- and 5-year stands of alfalfa on winter wheat yield

E. Campiglia, F. Caporali, P. Bàrberi and R. Mancinelli
Department of Crop Production, University of Tuscia
S. Camillo de Lellis, 01100 Viterbo, Italy

Summary

Legumes such as alfalfa (*Medicago sativa* L.) are fundamental components of organic cropping systems. The effect of 5-year long cropping sequences [sunflower (*Helianthus annuus* L.)-winter wheat (*Triticum aestivum* L.) 2-yr rotation; 3-yr Italian ryegrass (*Lolium multiflorum* Lam.) + 2-yr alfalfa; 2-yr Italian ryegrass + 3-yr alfalfa; 1-yr Italian ryegrass + 4-yr alfalfa; 5-yr alfalfa] on winter wheat yield was studied in Central Italy in a long-term experiment which started in 1992. Sowing date (standard and late) and mineral nitrogen fertilisation rate (0, 60 and 120 kg N ha^{-1}) applied to wheat were included as additional experimental factors. Winter wheat grain yield in the unfertilised preceding crop sequences ranged from 1.4 t ha^{-1} in the sunflower-wheat sequence to 3.7 t ha^{-1} following 5-yr alfalfa. When N fertiliser was applied, the wheat grain yield was increased irrespective of preceding crop sequences, the maximum yield being reached following alfalfa at 60 kg N ha^{-1}. Total N content in wheat grain was positively influenced by alfalfa stand age and N fertiliser rate. Results indicate that in a Mediterranean environment a satisfactory winter wheat yield can be achieved without any mineral N fertilisation provided that alfalfa is grown as a preceding crop for a minimum of 3 years. Inclusion of an alfalfa stand in organic cropping systems is therefore strongly recommended.

Introduction

Legumes such as alfalfa are fundamental components of organic cropping systems because they are particularly suited to make crop rotations less dependent from auxiliary energy inputs (Pierce & Rice, 1988) and they can positively influence the structure and functioning of the agroecosystem (Caporali & Onnis, 1992). Documented effects include reduction of disease, weed and insect infestations, increase in soil organic matter content, and enhancement of soil particle aggregation and water infiltration (Angers, 1992). Several studies have shown that improved crop yield and product quality usually emerge when alfalfa is grown as a preceding crop (Caporali & Onnis, 1992; Seliga & Shattuck, 1995; Anderson *et al.*, 1997; Holford & Crocker, 1997). One of the major effects of alfalfa is its well-known ability to fix symbiotically large amounts of atmospheric nitrogen (N_2), most of which is carried over to succeeding crops (Pantanelli, 1952; Bruulsema & Christie, 1987; Harris & Hesterman, 1990). The amount of N_2 fixed can range from 174 kg N ha^{-1} in the first growing year to 466 kg N ha^{-1} in the third year (Kelner *et al.*, 1997). An additional benefit of including alfalfa in a cropping sequence is its ability to extract and utilise NO_3^--N that has leached beyond the root zone of most annual crops (Schuman & Elliot, 1978). Although large amounts of fixed N are removed with forage harvest, significant quantities are added to the soil system with the incorporation of herbage and roots (Sheaffer *et al.*, 1991). In organic cropping systems, where one of the key points to achieve long-term sustainability is the replenishment of the N removed from the soil by agricultural products, the inclusion of alfalfa can be suitable to replace the majority of nitrogen taken up from the system. Wheat is the most widely grown winter cereal in central and southern Italy. Because of its high yielding ability, wheat is believed to have a large requirement for nitrogen and therefore to rapidly deplete soil N content. Few studies have documented the effects of alfalfa stands of different age on the performance of the subsequent wheat. Our objective was to determine the effects of 2-, 3-, 4- and 5-year stands of alfalfa on grain yield, grain protein content, and N fertiliser requirements of a subsequent wheat crop, in order to evaluate the potential of alfalfa to substitute for mineral N fertilisation.

Materials and methods

A field trial was conducted at the experimental farm of the Tuscia University in Viterbo, Central Italy (12°40'E, 42°26'N). The main soil characteristics (0-30 cm depth) at the beginning of the trial (year 1992) were: pH 6.9, organic matter 1.6%, total N 0.101%, available P_2O_5 22 mg kg^{-1} and exchangeable K_2O 136 mg kg^{-1}. Five different crop sequences were carried out for 5 years (from autumn 1992 to autumn 1997) before winter wheat (*Triticum aestivum* L.) was grown to determine their residual effect. The cropping sequences (Table 1) selected were the following:
(1) sunflower (*Helianthus annuus* L. *cv* HS 90) - winter wheat (*Triticum aestivum* L. *cv* Pandas) 2-yr rotation, fertilised annually with 120 kg N ha^{-1} (applied at hoeing in sunflower and at tillering in wheat), 100 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1};
(2) 3-yr Italian ryegrass (*Lolium multiflorum* Lam *cv* Asso), fertilised pre-sowing with 100 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1} + 2-yr alfalfa (*Medicago sativa* L. *cv* Maremmana), fertilised pre-sowing with 200 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1} and annually (on every autumn) with 50 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1};
(3) 2-yr Italian ryegrass + 3-yr alfalfa, fertilised as above;
(4) 1-yr Italian ryegrass, + 4-yr alfalfa, fertilised as above;
(5) 5-yr alfalfa, fertilised as above.

Table 1 Crop preceding sequences used for winter wheat.

		Crop				
Crop sequence description		**1993**	**1994**	**1995**	**1996**	**1997**
3-year sunflower + 2-year wheat	1	S	W	S	W	S
3-year ryegrass + 2-year alfalfa	2	R	R	R	A	A
2-year ryegrass + 3-year alfalfa	3	R	R	A	A	A
1-year ryegrass + 4-year alfalfa	4	R	A	A	A	A
5-year alfalfa	5	A	A	A	A	A

A= alfalfa; R= ryegrass; S= sunflower; W= wheat.

Mineral N fertiliser was used instead of organic fertiliser in order to better assess the capacity of alfalfa to provide the cropping system with nitrogen.

In all cropping sequences, alfalfa was mowed three times per year and Italian ryegrass twice per year, from the spring following crop establishment onwards, the biomass being removed in any cases. Sowing and mowing dates varied according to the seasonal conditions.

In autumn 1997, a split-split-plot experimental design, arranged in a randomised complete block layout with three replications, was superimposed on the plots where the preceding crop sequences were grown. Preceding crop sequences were allocated in the main plots, winter wheat sowing dates (standard and late) in the sub-plots and winter wheat N fertiliser rates (0, 60 and 120 kg N ha^{-1}) in the sub-sub-plots (6 by 3 m).

Mouldboard ploughing at 30-35 cm depth was performed in September 1997, and followed by seedbed preparation by disking (at 15 cm depth) and rotary harrowing at 7-10 cm depth in mid-October. Winter wheat (cv. Pandas) was sown at a rate of 220 kg ha^{-1} seeds in rows spaced 15 cm apart on two different dates (standard sowing on 10 November, and late sowing on 10 December). Phosphorus (100 kg P_2O_5 ha^{-1}) and potassium (100 kg K_2O ha^{-1}) fertilisers where applied to all plots immediately before the last harrowing pass. The three mineral N fertiliser rates were applied (as ammonium nitrate) as top dressing at the wheat tillering stage (27 February). Weeds were controlled by hand immediately after N fertilisation. In each sub-sub-plot, four 4 m-long central rows of wheat were harvested in mid-July to determine the straw and grain yields, which were expressed on a dry-matter basis following oven-drying at 70°C until constant weight. A 500 g grain sample per sub-sub-plot was ground on a 0.5 mm diameter sieve, and a sub-sample was used for determination of grain total N concentration by the Kjeldahl method.

Data were subjected to split-split-plot analysis of variance using the ANOVA procedure of the SAS program (SAS Institute, 1985). Means were separated by the least significant difference (LSD) test at $P \leq 0.05$. Regression analyses of wheat grain yield on alfalfa stand duration and N fertiliser rates were performed using the GLM procedure of SAS.

Results and discussion

Winter wheat grain yield was influenced by all the experimental factors – of which the preceding crop sequence was the most important – and a significant "preceding crop sequence × N fertilisation rate" interaction occurred. Compared with the sunflower-winter wheat 2-yr rotation, inclusion of alfalfa in the preceding crop sequence – regardless of the duration of the alfalfa stand – resulted in a significantly higher wheat grain yield across all N fertiliser rates (Table 2). In the plots which did not receive N fertiliser, the largest (164%) and smallest (93%) yield increase occurred after 5- and 2-yr alfalfa respectively, with the actual size of the effect decreasing progressively with the duration of the alfalfa stand, to such an extent that no statistically significantly differences ($P \leq 0.05$) were found among 3-, 4- and 5-yr alfalfa.

Table 2 Winter wheat grain yield (t ha^{-1}) as affected by preceding crop sequence and N fertilisation level.

Crop	N fertilisation level (kg ha^{-1})		
Sequence	0	60	120
1	1.4	2.3	3.2
2	2.7	4.3	4.0
3	3.4	4.1	4.3
4	3.5	4.6	4.4
5	3.7	4.3	4.5
LSD 0.95		0.6	

Winter wheat grain yield response to N fertilisation was higher for the sunflower-winter wheat preceding crop sequence than for any crop sequences including alfalfa. Consequently, wheat following alfalfa showed low requirement for additional N fertiliser to achieve maximum grain yields. Regardless of the duration of the legume stand, the unfertilised wheat which followed alfalfa yielded as much as wheat in rotation with sunflower when fertilised at the highest N rate. Therefore, a 120 kg N ha^{-1} fertilisation rate could be considered equivalent to the residual effect of a 3- to 5-yr alfalfa stand in the first year after incorporation of the legume biomass, the value for 2-yr alfalfa being some 90-100 kg N ha^{-1}. Despite the evident beneficial effect of alfalfa on soil N fertility, maximum wheat grain yield (about 4.5 t ha^{-1}) was reached after any alfalfa stands at 60 kg N ha^{-1}. This suggests that alfalfa had a beneficial effect on soil N fertility, which was complementary to that of mineral N fertiliser; this was probably associated with an enhancement of soil fertility *sensu latu*, as it is well known by farmers. The largest relative responses to the rate of 60 kg N ha^{-1} occurred following 2-yr alfalfa, in which grain yield increased from 2.7 t ha^{-1} (without N fertiliser) to 4.3 t ha^{-1}. The high N contribution of alfalfa to this cropping system signifies that, without the inclusion of alfalfa as a preceding crop, far more than 120 kg N ha^{-1} are presumably necessary in a cash crop sequence such as sunflower-wheat to reach maximum wheat grain yields. The standard sowing date generally decreased wheat grain yield in all cropping sequences (data not shown): this effect may have occurred because of the excessive soil moisture conditions encountered immediately before and after sowing consequent to a heavy rainfall period (Figure 1). Regression analyses of wheat grain yield at each N fertiliser rate on alfalfa stand duration (averaged over sowing dates) are shown in Figure 2. It is evident that, without N fertilisation, wheat grain yield increased by 0.2 t ha^{-1} for each additional year of alfalfa in the crop sequence, although the increase was less pronounced for the older alfalfa stands. This effect disappeared at the 60 and 120 kg N ha^{-1} fertiliser rates, where relatively high wheat grain yields were obtained in all crop sequences which included alfalfa.

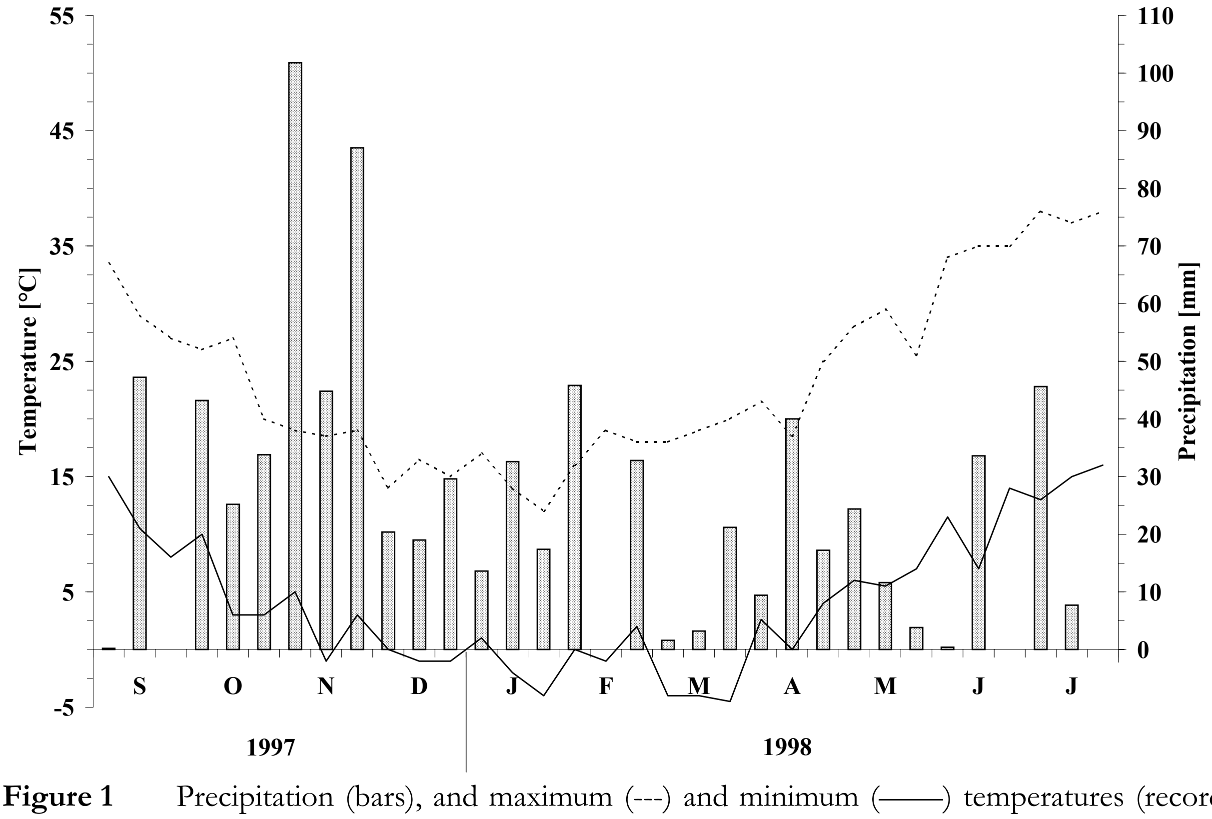

Figure 1 Precipitation (bars), and maximum (---) and minimum (——) temperatures (recorded at 10-day intervals) at Viterbo, during the 1997-98 wheat growing season.

The effect of preceding crop sequence on wheat straw yield was similar to that observed on wheat grain yields with the largest unfertilised yields following 5-yr alfalfa (Table 3). The effect of alfalfa stand duration on wheat straw yield was actually smaller than that on grain yield because of the statistically significant ($P \leq 0.05$) increase exerted on wheat harvest index (data not shown).

Both alfalfa stand duration and mineral N fertilisation had a large positive effect on wheat grain N concentration, but the interaction between the two factors was not significant (Figure 3). The highest N concentration occurred after 5-yr alfalfa (1.83%), but differences with the values observed for 3- and 4-yr alfalfa were not significant at $P \leq 0.05$. Grain N concentration was lowest in wheat following the sunflower-winter wheat 2-yr rotation (1.59%).

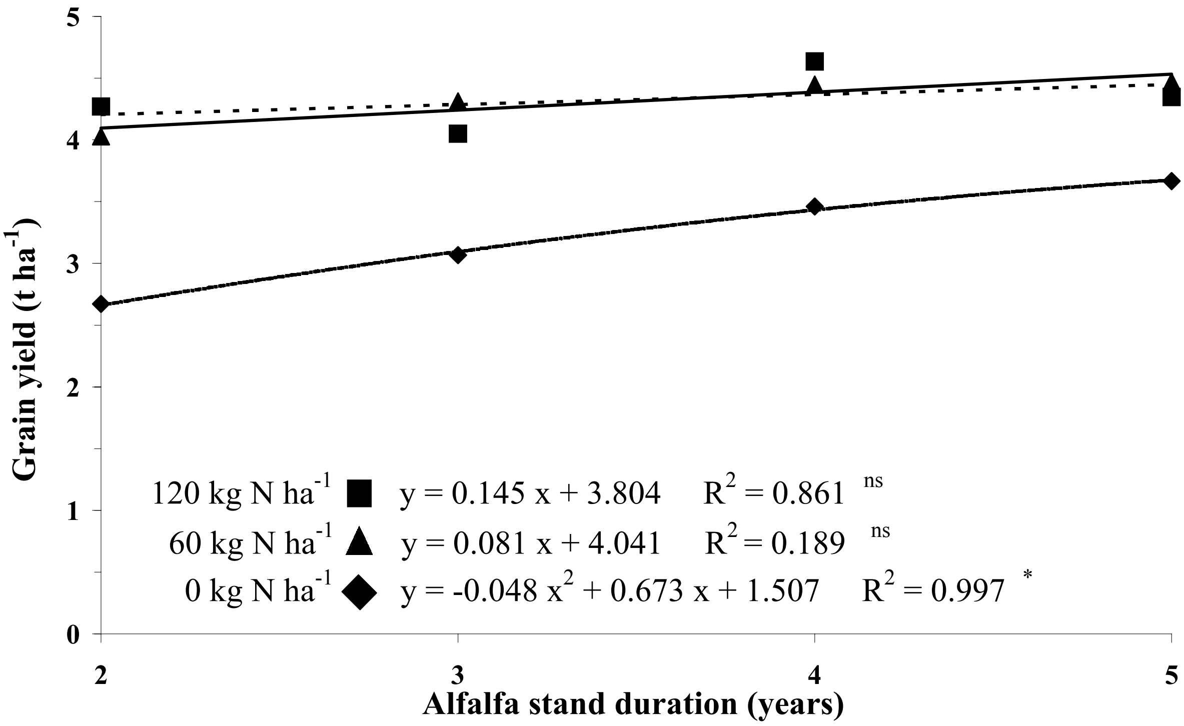

Figure 2 Relationship between wheat grain yield and alfalfa stand duration for different N fertiliser levels. * and ns denote significant and not significant effects at $P \leq 0.05$, respectively.

Table 3 Winter wheat straw yield (t ha^{-1}) as affected by preceding crop sequence and N fertilisation level.

Crop sequence	N fertilisation level (kg ha^{-1}) 0	60	120
1	2.3	3.4	4.7
2	3.9	6.4	5.8
3	5.5	5.9	6.5
4	5.0	6.6	6.5
5	5.7	6.2	7.0
LSD (P≤ 0.05)		0.7	

In conclusion, in the absence of mineral N fertilisation applied to wheat, the preceding crop sequences that included alfalfa were clearly the most effective in increasing grain yield and grain N concentration of the cereal. Surprisingly, the 3-, 4- and 5-yr alfalfa stands resulted in similar residual effects; it remains to be seen whether this substantial equivalence would persist over time. The results obtained in this research confirm that satisfactory winter wheat yield can be achieved without any direct N fertilisation in a Mediterranean environment, provided that alfalfa is grown as a preceding crop (Caporali & Onnis, 1992). Alfalfa is thus particularly suited to be included in organic cropping systems where maximum exploitation of natural resources is sought for.

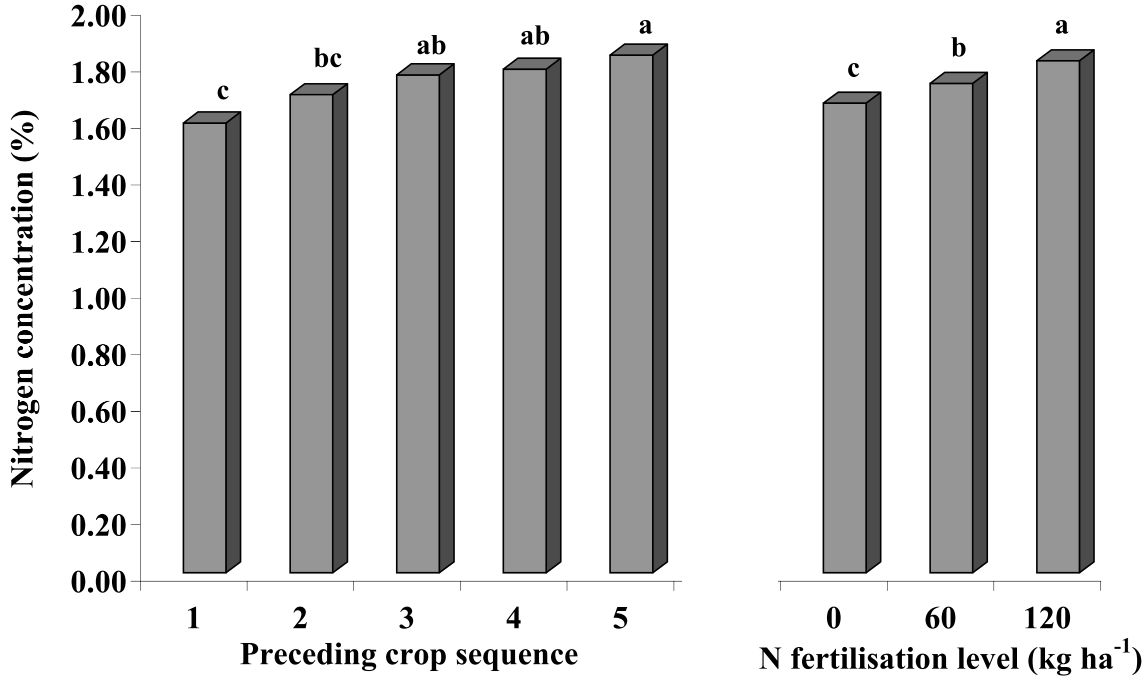

Figure 3 Nitrogen concentration (%) in wheat grain after different preceding crop sequences and fertilisation levels. Bars labelled with the same letter are not significantly different at $P \leq 0.05$.

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Measurement of nitrogen partitioning within different organic systems incorporating strip intercropping, sheep and crop rotation

S.A. Jones, P.M. Harris and M.J. Gooding
Crops Research Unit, Department of Agriculture, The University of Reading
Earley Gate, PO Box 236, Reading, RG6 6AT, UK

Summary

The potential benefits of an organic farming system utilising strip intercropping, and the possible transfer of nitrogen, via grazing sheep, from a clover-rich grassland strip to associated vegetable crops were investigated. The vegetable crops were cabbage and carrots (1994), and turnips and celery (1995). Immediately after each of the vegetable harvests, sheep grazed half of the vegetable strips along with the associated clover rich grass strip. To assess the longer term effects, the whole site was planted with cereal test crops in 1996 (wheat) and 1997 (oats). The soil NO_3-N and NH_4-N contents were measured pre and post the first three growing seasons, and the yield and total N content of all herbage and crop production were monitored. The short, medium and longer term effects of including sheep in the system, and of using different ratios of associated inter-cropped strips, were both investigated. In the third and fourth years the benefits of the above, in terms of N present within the system, were compared to the normal farm procedure of three years grass-clover ley followed by three years vegetable production. In 1994 and 1995 grazing increased the N uptake of the later sown vegetable crops and affected the N taken up by the wheat test crop. In 1994, 1995 and 1996 the residual soil mineral N content of the vegetable strips was significantly increased by grazing and in the later two years there was some effect of varying the ratio of area of grass-clover to vegetable crop. However, as anticipated, the major benefit of the grass-clover ley was realised through nitrogen released following ploughing in March 1996. Rotation was the only significant, although somewhat reduced, effect on the N uptake of the oat crop in 1997.

Introduction

Intercropping is the growing of two (or more) crops simultaneously on the same area of ground (Willey, 1979). The benefit derived from such systems depends on many factors including the spatial relations and densities of the crops in question. However, since a shortage of nitrogen is a major constraint to crop growth, a common feature of intercropping systems is the combination of nitrogen-fixing leguminous crops with non-legumes. The method of utilising nitrogen fixation by legumes for the benefit of non-leguminous crops commonly employed by organic farmers is that of crop rotation. With intercropping however, nitrogen fixed by the legume may be available to the other crop(s) during the course of growth, rather than only after the legume has been ploughed in the customary rotational sequence. The aim of this field experiment was, therefore, to determine to what extent nitrogen fixed by a grass-clover ley could be transferred to intercropped vegetables during the course of growth and whether such transfer would compare favourably with the release of nitrogen to a crop following ploughing. The transfer of nitrogen from a legume to a non-legume by intercropping would depend upon either, whether nitrogen fixed by the legume component was made available to the non-legume by excretion or through the decay of plant parts, or whether the legume made less demands upon available soil mineral nitrogen (without sacrificing yield), which could then be utilised by the non-legume (Stern, 1993). The degree to which such transfer or enhanced availability of soil mineral nitrogen might occur would seem to depend also on the intimacy of association of the intercrops.

An alternative method of transferring nitrogen would be to utilise grazing animals and strip intercropping. Strip intercropping can be defined as growing two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough to interact agronomically (Vandermeer, 1989). The principle here would be to intercrop strips of vegetables with strips of a grass-clover mixture. After harvesting a vegetable crop, the grass-clover and the residues from the vegetable crop would be grazed. In the course of this some of the nitrogen from the grass-clover component would be transferred through the deposition of dung and urine, which would then enhance the supply of nitrogen for the next vegetable crop. In this system, there would be a time-lag in the transfer of nitrogen to the vegetable crop. However, the crop and the legume would remain on their respective areas and not rotate, thus avoiding the significant loss of nutrients associated with ploughing up a leguminous crop. In addition, many organic farmers prefer minimal cultivations to ploughing because of the less drastic effect on the soil environment (Blake, 1994). Such a system might also be expected to influence the incidence of pests and diseases - although perhaps not always in favour of the crop involved (Vandermeer, 1989). This experiment combined the three elements of intercropping (i.e. strips of grass-clover ley and vegetable crops), livestock grazing and crop rotation. The potential benefits of the system attributable to the nitrogen economy of the crops could derive from the following three sources:

1. Transfer of nitrogen during the course of growth;
2. Transfer by grazing involving a time-lag in transfer;
3. Transfer after ploughing in a normal rotational sequence.

The benefits to be derived from (1) clearly depend upon the intimacy of the intercrops and whether nitrogen is the only factor involved in the interaction between the components of the intercrop. For (2) the ratio of the areas devoted to the vegetable and grass-clover ley will clearly be important; consequently both this and the intimacy of association (1) were incorporated into the design of the experiment. For (3) both vegetable and legume strips were ploughed up after a sequence of cropping and the residual effects tested in successive cereal crops.

In terms of the intimacy of association of the intercrops, it was reasoned that the component crops should be grown in modules with a minimal width of two meters, within which four rows of vegetables could be accommodated. Since the greatest degree of intimacy would occur on the rows of vegetables adjacent to the legume then each row would be harvested separately. In the case of the transfer by grazing, the ratio of the area occupied by the legume to that of the vegetable intercrop was varied. This would affect the amount of legume offered to the grazing animal and, therefore, the amount of nitrogen available for transfer.

Materials and methods

The experiment was carried out between October 1993 and September 1997 at Path Hill Farm, near Pangbourne, Berkshire, England (0°54'W, 51°29'N). The soil is Sutton Series 2, a coarse loamy soil, usually over gravel, but locally containing clay and flints. The site had been used for organic vegetable production during the three years prior to October 1993 and before this had been a grass-clover ley as part of a six year rotation. In October 1993 the area was ploughed up and the clover rich grass strips were sown with white clover (cv. Alice @ 9.0 kg ha^{-1}) and perennial ryegrass (cv. Portstewert @ 22.4 kg ha^{-1}). Clover establishment was poor following adverse weather conditions and additional seed was sown in March 1994 (11.1 kg clover ha^{-1} and 3.1 kg perennial ryegrass ha^{-1}). The husbandry of the vegetable and herbage crops was carried out by the resident organic grower. In 1994 and 1995, an experimental plot was made up of a strip of grass-clover mixture and an adjacent strip of vegetables. The strips consisted of one, two or three 2 m wide 'modules'. In 1996 all modules were sown with a test crop of spring wheat (cv. Axona) followed, in 1997, by a further test crop of spring oats (cv. Aberglen). The nitrogen contents of all plant materials that were removed from, or harvested and returned to, the experiment were estimated, including the amount of nitrogen taken up by the sheep. In addition, the status of the soil NO_3-N and NH_4-N were monitored on six occasions (Method 53; MAFF, 1986). Stone free bulk density was 1.27 and 1.16 g cc^{-1} at 0-30 and 30-60 cm depths respectively in areas adjacent to the plots. Soil P, K and pH were measured on three occasions (Methods 59, 63 and 32; MAFF, 1986).

Vegetable strips

Two vegetable crops were grown in each of the first two years of the experiment. The five crops chosen, (turnips replaced an initial sowing of beetroot, which had suffered extreme predation by slugs, in April 1995), were selected according to the following criteria: Short time to mature after planting; any harvest residues are both palatable and harmless to sheep; financial benefits are maximised because of consumer demand for the crops chosen. The vegetable crops chosen were cabbage, carrot, turnip (beetroot replacement) and celery. The cabbage and celery crops were transplanted from nursery beds, which may be an advantage in terms of the timings involved in this system. To prevent bird damage and to hasten development the vegetable strips were covered with fleece (Groshield Nonwoven Crop Cover, 3.2 m wide). Weeds were controlled with a combination of a mechanical rotovator for seed bed preparation, and hand weeding. Each 10×2 m vegetable module consisted of four rows of vegetables with a spacing of 50 cm between each row. Each row within a module was harvested and processed separately. After measured discards had been removed from the ends of each row, 4×0.5 m samples were harvested at measured intervals along the row. The resulting 1 m^2 samples were separated into economic and residual yield components which then had their dry matter determined gravimetrically. The N concentration was determined with an oxidative combustion method (Association of Official Analytical Chemists, 1990) using an automated Dumas type combustion analyser (Leco Instruments (UK) Ltd., Stockport). The economic yield of the remaining plants from each row was measured and then removed from the area. The residues were returned to the plots, either to be grazed, or cultivated in. The N contents of both crop components were then used to calculate the amount of N removed from the system, the amount available to the sheep when grazing the residues, and the amount of N returned to the non-grazed strips.

Grass-clover ley strips

Galvanised metal sheep fencing (1 m high) was used to contain sheep within the strips to which they were allowed access. The resident flock of sheep (Welsh Mountain Mule / Suffolk cross) were used to graze the relevant strips immediately after the vegetables had been harvested and continued to graze until the majority of the clover had been eaten. Following each of the four vegetable harvests, the mean weight of the sheep used and the duration of grazing were; 45 kg, 2 days; 34 kg, 8 days; 46 kg, 8 days and 26 kg, 8 days, respectively. One sheep was used for each 2×10 m module of grass-clover. Lister 12V electrical sheep shears were used to harvest two 0.5 m^2 samples from each 2×10 m grass-clover module, before and after each of the four occasions on which the grazing treatment was applied. The total dry matter and N contents of the grass, clover and weed components were determined gravimetrically. The total dry weight of plant material eaten by the sheep during grazing, and hence the total N ingested, were then calculated. On four occasions, dead plant material was an added component following the necessity to cut the top growth of the legume mixture midway through the vegetable growth. The cutting was carried out using a conventional 45 cm wide rotary mower and was done on four different occasions. All of the sheep were removed from the plots at the same time.

Test crops

In March 1996, following the two years of strip intercropping, each of the 2×10 m modules from both the grass-clover and vegetable strips were sown with a test crop. The experimental area was ploughed with a conventional two-furrowed plough and cultivated with a tractor mounted rotary cultivator. The original 2×10 m modules were then remarked and drilled with spring wheat using a 2 m wide, Trialsmaster self propelled experimental plot drill. In August 1996 the wheat crop was harvested with a Wintersteiger Nurserymaster Elite small plot combine. The resulting grain and straw samples had their total dry weights and N contents determined. The same procedure was followed in 1997 when a spring oat crop was used.

Treatments

The three treatment factors (Table 1) were
(a) Size - the width of the grass-clover and vegetable strips, each 2, 4 or 6 m wide. The ratio of one to the other was also varied. In order to gauge the effect of the clover on the system a 2 m wide, 'no clover' treatment was also included.
(b) Grazing - the plots where sheep had access to the vegetable strips were described as 'grazed', as opposed to 'non-grazed'. This applied to both the grass-clover and vegetable strips.
(c) Row position - not actually applied in the field but used when analysing the effect of the proximity of the herbage strip on the vegetable rows. Each vegetable row was harvested separately and preliminary analysis of the vegetable row data indicated that any influence of the herbage strip was confined to the immediately adjacent rows. Consequently, the vegetable row data was analysed with two levels of row position, i.e. 'inner' and 'outer' rows. The main plot treatments were the six levels of the 'size' treatment, and following the cabbage crop harvest in July 1994, each main plot was split in accordance with the grazing regime. The grazing treatments were therefore sub-plots in a split plot design and this was used as the basis for the analysis of subsequent vegetable, grass-clover, cereal and soil data. In July 1994 the cabbage row 'position' was considered to be a sub-plot of the 'size' treatment. The row 'position' of the carrot, turnip and celery data was regarded as a sub-plot of the grazing treatment, in a split-split-plot design. All suitable data sets were subject to appropriate analyses of variance and standard error of the differences (s.e.d.) between means calculated (GENSTAT 5 Committee 1993).

Table 1 Treatments.

Size of plot	Grazing of vegetable strip	Position of rows (Vegetable strips only)
L_{2m} V_{2m}	Grazed	Inner Outer
	Non-grazed	Inner Outer
L_{4m} V_{2m}	Grazed	Inner Outer
	Non-grazed	Inner Outer
G_{2m} V_{2m}	Grazed	Inner Outer
	Non-grazed	Inner Outer
L_{2m} V_{4m}	Grazed	Inner Outer
	Non-grazed	Inner Outer
L_{4m} V_{4m}	Grazed	Inner Outer
	Non-grazed	Inner Outer
L_{6m} V_{6m}	Grazed	Inner Outer
	Non-grazed	Inner Outer

L = clover rich grass ley, G = grass only, V = vegetables

Results and discussion

N content of crops harvested from the vegetable strips

In November 1994, the N uptake by the carrots on the strips where cabbage had previously been grazed was 41.5 kg N ha^{-1} compared to only 36.4 kg N ha^{-1} on the non-grazed strips ($p<0.001$). This 14% increase compares with only a 7% increase in DM yield, so grazing increased nitrogen concentration ($p=0.035$). However, there was no significant effect of grazing on the amount of N taken up by the turnip crop by July 1995. This could suggest that it was the nitrogen immediately available in urine, which was responsible for the main benefit of grazing to the carrots, and this was lost over the following winter. This is, however, simplistic because the grazing treatment benefited the subsequent test crop of spring wheat. It is possible that this benefit may have accrued from slowly available nitrogen in the dung rather than from the urine.

In November 1995, grazing increased the amount of N taken up by the celery crop by 19% ($p=0.003$). Any possible advantage that the outside rows of vegetables may have had due to their close proximity to the grass-clover strips can clearly be dismissed. A mean total of 209 kg N ha^{-1} was taken up by the inside rows of the four vegetable crops, a 44% advantage over the outside rows ($p<0.001$).
In August 1996 there was a highly significant effect of rotation ($p<0.001$), whereby the spring wheat harvested from the previous vegetable strips recovered 33% less N than the mean 133 kg N ha^{-1} taken up by the wheat grown on the previous grass-clover strips. There was a significant interaction between rotation and grazing ($p=0.005$). Where the sheep had previously had access to the vegetable strips 9%

more N was recovered by the wheat crop than where access had been denied. There was a 4% decrease in N uptake by the wheat on the corresponding herbage strips (Table 2). There was also a significant interaction between size and rotation (p=0.029) as regards the N taken up by the wheat. The maximum advantage of this interaction was the 17% more N removed from the vegetable strip of treatment L_4V_2 than that of treatment L_2V_4.

Table 2 The effect of the interaction between rotation and grazing on the total amount of N (kg ha^{-1}) recovered by the wheat crop, August 1996.

Previous crop	Grazing: Grass-clover + vegetable residues	Grazing: Grass-clover only	Difference
Vegetables	93	85	+8
Grass-clover	130	135	-5

s.e.d. 3.6 (2.9 for comparing grazing treatments within same levels of rotation) p<0.01.

The mean total N recovered by the second test crop of oats in August 1997 was 50 kg ha^{-1}. Rotation was again highly significant (p<0.001). The oats grown on the previous grass-clover strips recovered 57 kg N ha^{-1} as opposed to 44 kg ha^{-1}, where the vegetables had previously been grown. This 22% reduction in N recovered compares with the 33% reduction on the corresponding strips, by the previous test crop in August 1996 and demonstrates that treatment effects were lessening. In confirmation, there were no other significant treatment effects on the total uptake of N by the oat crop.

Table 3 The effect of the grazing treatment on the soil mineral N content of the vegetable strips, November 1995.

Layer	NO_3-N		NH_4-N		NO_3-N + NH_4-N	
	Grazed	Non-grazed	Grazed	Non-grazed	Grazed	Non-grazed
0 - 30 cm	16	8	17	11	33	19
30 – 60 cm	13	6	15	11	28	17
0 – 60 cm	29	14	32	23	61	36
	s.e.d. and significance of grazing treatment					
0 – 30 cm	1.4^{***}		1.8^{**}		2.9^{***}	
30 – 60 cm	1.2^{***}		1.3^{*}		2.0^{***}	
0 – 60 cm	2.3^{***}		2.0^{***}		3.9^{***}	

Levels of significance: * p<0.05; ** p<0.01 ; ***p<0.001

Soil mineral N content of the vegetable strips 1994-95

In November 1994 there was a highly significant effect of grazing ($p<0.001$) on the vegetable strips, when comparing soil NO_3-N content to a depth of 60 cm with the measurements made in the previous March. This was mainly due to a 4.5 kg N ha^{-1} increase in the NO_3-N content of the 30-60 cm soil layer of the grazed strips, as opposed to a 1 kg ha^{-1} reduction in the corresponding non-grazed vegetable strips ($p=0.011$). In November 1995, grazing had significantly affected both components of the soil mineral N content, in both horizons and in total (Table 3). The largest individual effect of grazing was the 51% extra NO_3-N present in the 0-30 cm soil layer of the grazed vegetable strips ($p<0.001$). There was also 15% more total soil mineral N in this layer ($p<0.001$). When considering the total top 60 cm of soil under vegetable strips grazing increased NO_3-N, NH_4-N and total soil mineral N by 53%, 31 % and 42 % respectively ($p<0.001$ for all three; Table 4). At this time there was also a size × grazing interaction ($p=0.031$) because grazing had a large positive effect on L_4V_2 but no effect on L_2V_4 (Table 4).

Table 4 The effect of the size treatment on the advantage exhibited by the grazing treatment in terms of the total soil mineral N content of the vegetable strips (kg ha^{-1}), to a depth of 60 cm, in November 1995.

Size	Grazed	Non-grazed	Difference
L_2V_2	54	44	+11
L_4V_2	91	38	+53
G_2V_2	53	31	+22
L_2V_4	39	38	+ 1
L_4V_4	60	34	+26
L_6V_6	68	32	+36
Mean	61	36	+25
s.e.d. (a)†	3.9	$p<0.001$	
s.e.d. (b)‡	9.6	$p<0.05$	

L = clover rich grass ley, G = grass only, V = vegetables
† s.e.d. (a) for comparing grazing means
‡ s.e.d. (b) for comparing grazing treatments within a single size treatment

Soil mineral N content of all strips 1996

After the ploughing in March 1996 it was possible for the first time to measure the effect on soil mineral N content of the more conventional organic rotation. The amount of soil mineral N prior to drilling the spring wheat was 68 kg N ha^{-1} after grass-clover, i.e. 33% more than after vegetables ($p = 0.002$), 68% of this advantage was in the 0-30 cm soil profile.

After the wheat, in September 1996, 79 kg soil mineral N ha^{-1} was present where the grass-clover ley had been previous to the wheat, 21 kg N ha^{-1} more than where the vegetables had been ($p<0.001$).

The above results demonstrate the potential for this system to maximise the utilisation of the N fixed by the legume crop. The use of grazing animals to distribute the legume N influences the timing of the release of this N, and the minimal cultivation methods involved avoid the major nutrient losses following ploughing. The loss of nutrients from the system could be further reduced by the refined use of management tools, such as choice of vegetables according to rooting depth, and the optimisation of the necessary management of the grass-clover sward, perhaps including mulching.

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Dinitrogen fixation and residue nitrogen of different managed legumes and nitrogen uptake of subsequent winter wheat

R. Loges[1], A. Kaske[2] and F. Taube[2]
[1] *Department of Organic Farming, University of Kiel, Germany*
[2] *Department of Grass and Forage Science, University of Kiel, Holzkoppelweg 2, 24118 Kiel, Germany*

Summary

Fixed nitrogen accumulated by legumes is the main nitrogen source for organic farming systems. Knowledge about the amount of fixed nitrogen, its pathways into forage yield, crop residues, soil-N and yield formation of the following crop is needed for designing crop rotations.

Two field experiments were conducted in Northern Germany with differently managed (cut, mulched) legumes (red clover, alfalfa, white clover) in pure stands and various mixtures with two companion grasses (*Lolium multiflorum*, *Lolium perenne*) have been grown to determine N_2-fixation, residue nitrogen and N-uptake of subsequent crops.

Cropped grass/legume reached higher N_2-fixation than mulched. While green manure grass/legume left up to 280 kg N ha^{-1} in mulch, stubble and roots on the field, most cropped grass/legume mixtures left less than 110 kg N ha^{-1} in crop residues. Pure legume swards or legume rich mixtures showed higher N_2-fixation than grass rich mixtures. N-uptake in late autumn and at maturity of the subsequent wheat was strongly correlated to the legume content in DM-yield.

Introduction

Symbiotically fixed nitrogen accumulated by legumes is the main nitrogen source for organic farming systems. In crop rotations forage legumes like red clover (*Trifolium pratense*), alfalfa (*Medicago sativa*) and white clover (*Trifolium repens*) show higher nitrogen fixation than grain legumes like peas or faba beans (Larue & Patterson, 1981; Hagmeier, 1986). Forage legumes are self sufficient with nitrogen, their N_2-fixation can cover the nitrogen demand of several subsequent non-N_2-fixing crops (McBratney, 1981; Bowley *et al.*, 1984).

In Northern Germany red clover mixed with perennial ryegrass (*Lolium perenne*) or Italian ryegrass (*Lolium multiflorum*) is the main forage legume grown in crop rotations. Red clover/grass is usually cut 3 times for silage for winter forage or grown as green manure on set aside land with the possibility to receive EU-subsidies. Grass-clover mixtures for grazing are rare, because German farms usually have a high proportion of permanent pasture and the average stocking rate on German organic farms is low. As the EU does not pay subsidies for growing grass-clover for forage use and the subsidies for set aside land are low, especially arable farmers try to build up crop rotations where fixed N by legumes is used efficiently to keep the percentage of grass-clover in the crop rotation as low as possible.

There are two pathways for the nitrogen fixed by forage legumes to meet the N-demand of the following crops:

- directly by mulch, stubble and roots,
- indirectly by slurry or stable manure after feeding the conserved ensiled legume herbage.

For designing crop rotations with a high nitrogen use efficiency, knowledge about the amount of fixed nitrogen, its pathways into forage yield, crop residues, soil-N and yield formation of the subsequent crops for different managed legumes is necessary. For this reason the following field experiments have been designed.

Material and methods

The two field experiments were conducted on a sandy, loamy cambisol (14% clay) at the experimental station Hohenschulen near Kiel in Northern Germany (9°37'E, 54°21'N). Results are presented mainly from the growing seasons of 1994 to 1998. Annual precipitation was 905, 638, 522, 685 and 987 mm in 1994, 1995, 1996, 1997 and 1998 respectively. The following annual mean temperatures have been recorded: 9.2°C (1994), 8.7°C (1995), 7.1°C (1996) 8.8°C (1997) and 8.8°C (1998).

Experiment 1

The aim of experiment 1 was to determine the effect of forage legume species, seed mixture and management on yield, N_2-fixation, residue nitrogen and preceding crop value of legume/grass mixtures. The experiment includes the following factors:

1. Management (form of use)
   4 × cropped (forage production)
   2 × mulched (green manure)
2. Legume species
   white clover (cv. Milkanova)
   red clover (cv. Maro)
   alfalfa (cv. Planet)
3. Seed mixture

pure legume	white clover: 6 kg ha^{-1}, red clover: 12 kg ha^{-1} or alfalfa: 24 kg ha^{-1}.
legume/grass mixture	white clover: 4 kg ha^{-1}, red clover: 8 kg ha^{-1}or alfalfa: 16 kg ha^{-1} in mixture with perennial ryegrass: 20 kg ha^{-1} (cv. Mandat).
pure grass	perennial ryegrass: 30 kg ha^{-1} (cv. Mandat) as reference crop for measurement of N_2-fixation

All swards were established in mid August in each of the following years: 1996, 1997 and 1998 in open sowing in four replications. The plot size was 9 × 10 m. No fertiliser was applied, all swards were hand weeded. After one growing season the swards were ploughed without stubble breaking at two different dates (end of September/end of October). Winter wheat (cv. Orestis) was sown immediately afterwards with a rate of 290 seeds m^{-2} (end of September) or 350 seeds m^{-2} (end of October).

Experiment 2

The aim of experiment 2 was to determine the impact of companion grass species, seed rate and management on yield, N_2-fixation and preceding crop value of red clover/grass. The experiment included the following factors:

1. Seed mixture:
   100% red clover (cv. Maro) 12 kg ha^{-1}
   67% red clover + 33% grass 8 kg ha^{-1} +10 kg ha^{-1}
   33% red clover + 67% grass 4 kg ha^{-1} +20 kg ha^{-1}
   100% grass 30 kg ha^{-1}
2. Companion grass:
   Italian ryegrass (cv. Malmi) (representing a very high competitive companion grass)
   perennial ryegrass (cv. Mandat) (with a lower competitiveness than Italian ryegrass)
3. Seeding date / Duration of ley / Management (form of use) :
   august 1993 / 2-years / 1994/95: 4/4 cuts (forage production)
   august 1994 / 1-year / 1995: 4 cuts (forage production)
   august 1994 / 1-year / 1995: 2 mulching cuts (green manure)

The swards were established in each year in open sowing in four replications. The plot size was 9 × 12 m. No fertiliser was applied, all swards were hand weeded. After one/two growing season(s) swards were ploughed without stubble breaking at two different dates (end of September/end of October 1995). Winter wheat (cv. Orestis) was sown immediately afterwards with a rate of 290 seeds m^{-2} (end of September) or 350 seeds m^{-2} (end of October).

Determined parameters

In both experiments the following parameters were determined:

- crop yield and clover content of each cut,
- organic matter of stubble, roots (depth 0 - 30 cm) and mulch before ploughing,
- forage quality parameters of herbage, N-content of all plant material,
- $CaCl_2$-extractable mineral and organical soil-N (depth 0 - 90 cm) before ploughing,
- N_2-fixation (Total-N-difference method (Hardy & Holsten, 1975) based on the N-amounts in harvested plant material, crop residues and the $CaCl_2$-extractable soil-N fractions with the pure grass swards as reference crops),
- grain yield, total dry matter before winter in autumn and at maturity of winter wheat,
- N-content/crude protein concentration in wheat vegetative tissue material and grain.

Results and discussion

In experiment 1 the different combinations of the factors legume species, seed mixture and management showed highly significant effects on production of dry matter, harvested N, N in crop residues and N_2-fixation of swards with forage legumes. Also grain yield of the subsequent winter wheat was influenced by these factors. The chosen factors had no effect on grain protein content of winter wheat.

Figure 1 shows the effect of different combinations of legume species, seed mixture and management on DM-production, harvested N-yield and the N-amount in crop residues. Under both managerial systems grass/legume-mixtures showed higher production of dry matter than pure legume stands. In all mixtures and managerial systems white clover reached significantly lower yields than alfalfa or red clover. Under both managerial systems the red clover/grass mixture achieved the highest dry matter production.

While in the green manure system the whole plant material after mulching remained on the field, at least 250 kg N ha^{-1} were harvested from each of the cropped legume stands. The swards with white clover showed significantly lower N-yields than the swards with alfalfa or red clover. Pure red clover and pure alfalfa as well as the red clover/grass mixture gave highest yields.

After one growing season the cropped swards left about 105 kg N ha^{-1} on average in crop residues (roots and stubble) on the field. There were no significant differences between the cropped stands. The green manure swards left at least 210 kg N ha^{-1} in form of mulch, roots and stubble on the field. Due to a very well developed, by the first mulching cut not negatively affected net of stolons, the mulched swards with white clover left higher nitrogen amounts than the swards with alfalfa or red clover.

Figure 2 shows the highly significant interactions of legume species, seed mixture and management on N_2-fixation calculated with the Total-N-difference method based on the N-amounts in harvestable plant material, mulch and crop residues under consideration of the $CaCl_2$-extractable soil-N fractions. All cropped swards fixed higher amounts of N than the mulched ones. With an average of 330 kg N ha^{-1} the cropped swards with alfalfa or red clover fixed at least 50 kg N ha^{-1} more than the cropped swards with white clover. In the mulched system the stands with white clover reached higher fixation rates than the swards with the other two legume species.

Figure 2 also presents the effect of various combinations of legume species, seed mixture and management on grain yield and crude protein content of winter wheat following forage legume stands. Wheat following mulched grass/legume swards showed higher grain yields than wheat after cropped swards. A reason for this may be the higher amounts of N in the not harvested plant parts of the green manure stands. The grain yield of winter wheat after mulched swards was not significantly affected by the choice of preceding legume species or seed mixture. With a cropped sward as preceding culture the grain yield was nearly 1 t ha^{-1} higher with white clover than with red clover or alfalfa as preceding legume. As all preceding cropped swards left the same amounts of residue nitrogen on the field, a reason for grain yield differences may be different C/N ratios or N concentrations in the crop residues of the different swards.

Without additional fertilisation none of the different combinations of legume species, seed mixture and management reached the crude protein content of baking wheat. After a calculation of the amount of N removed from the field with wheat grain based on grain yield and crude protein content, 100 kg N ha^{-1} will be removed after green manure, while after cropped grass/legume 80 kg N ha^{-1} were removed from the field. A comparison of the removed N in grain with the N inputs through roots, stubble and mulch of the preceding legume sward showed a higher nitrogen use efficiency after cropped than after mulched swards.

The high nitrogen input from green manure of at least 210 kg N ha^{-1}, and the difference between N-input and N-output after these swards of at least 110 kg N ha^{-1} indicates an increased the risk of nitrate leaching after green manure incorporation as well as after grain harvest.

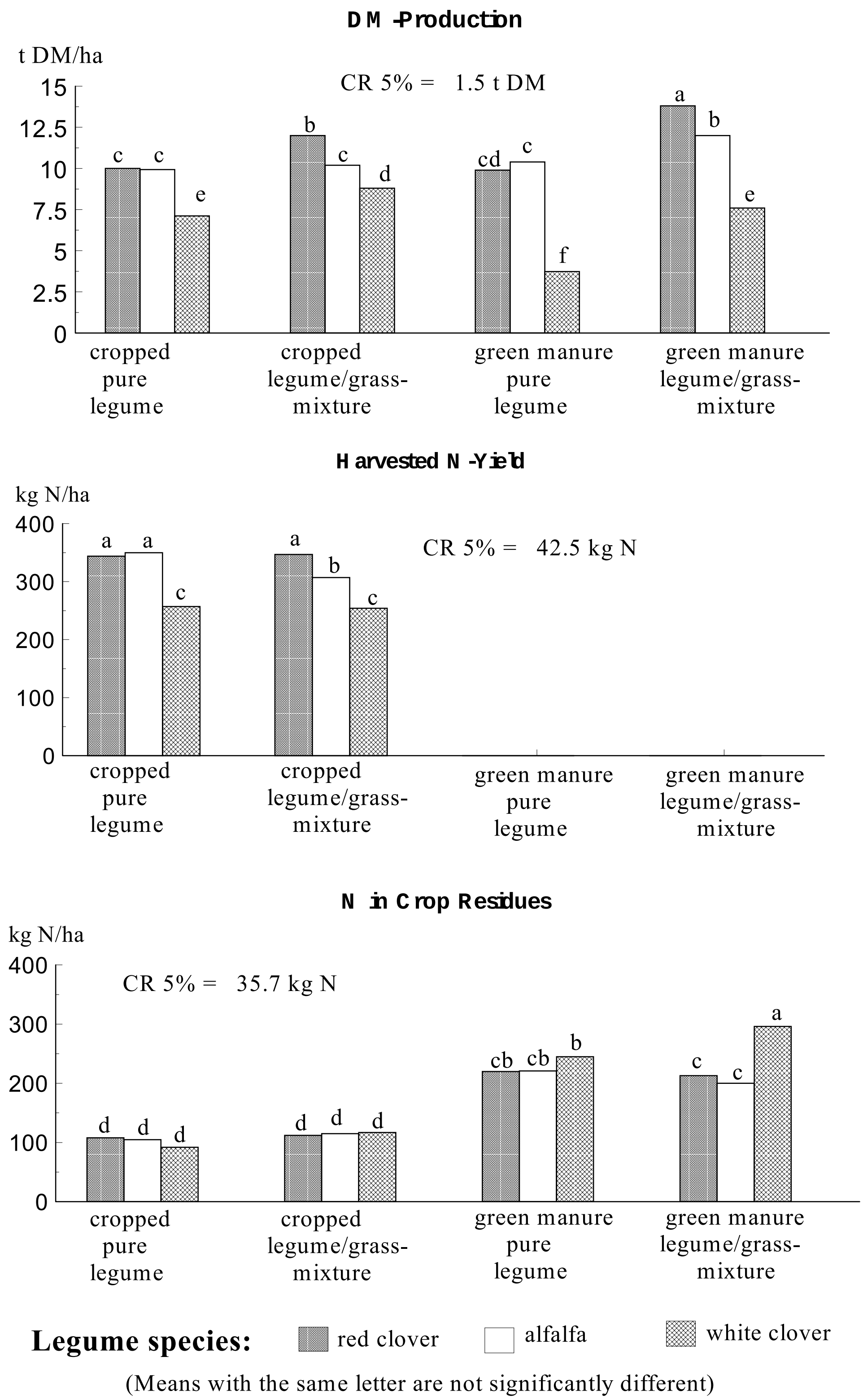
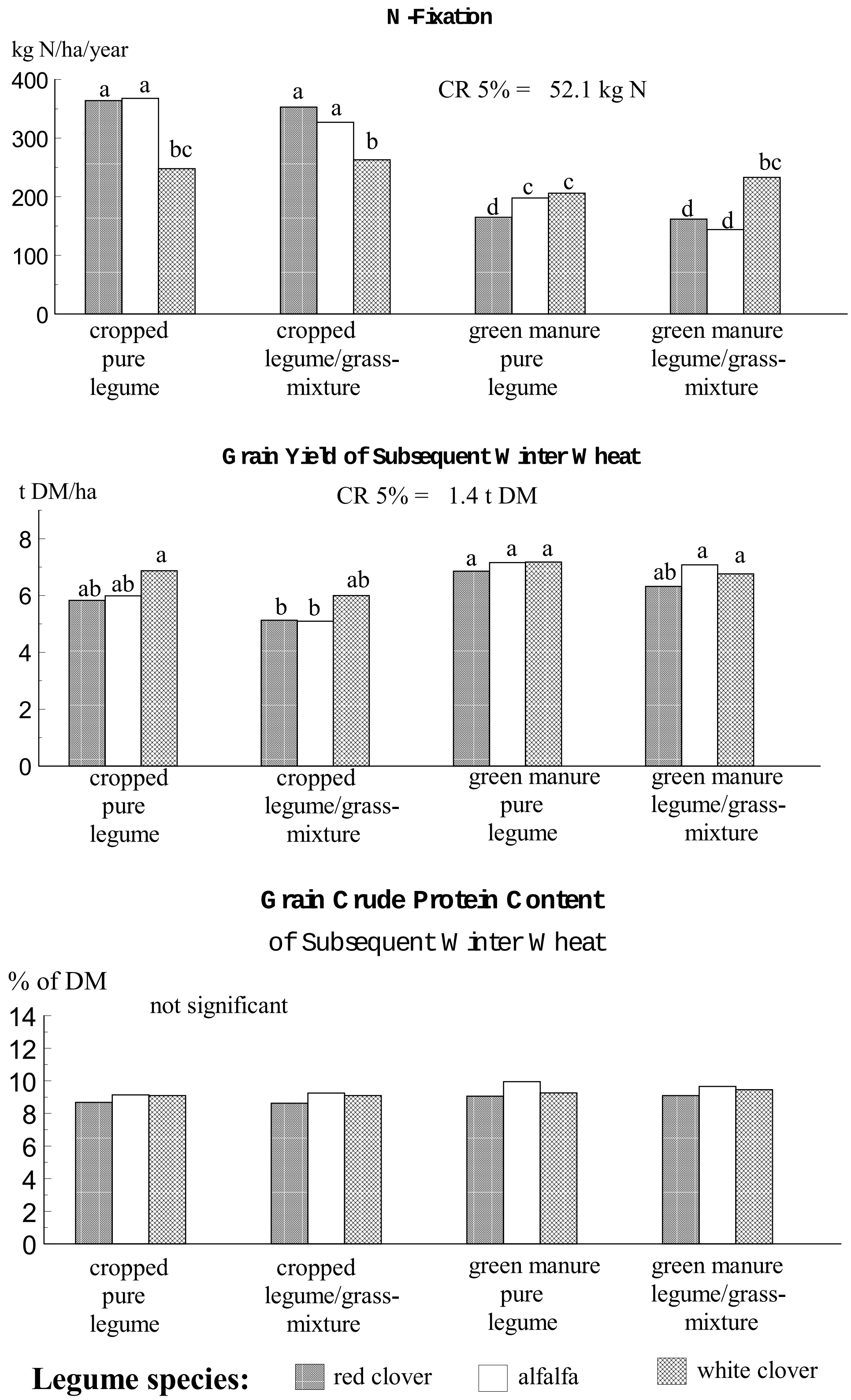


Figure 1 Effect of management on dry matter production, harvested N-yield and N in crop residues of three legume species in two different seed mixtures (Hohenschulen 1997).



(Means with the same letter are not significantly different)

Figure 2 Effect of management, legume species and seed mixture of legume/grass on N_2-fixation (Hohenschulen 1997) and on grain yield and grain crude protein content of subsequent wheat (Hohenschulen 1998).

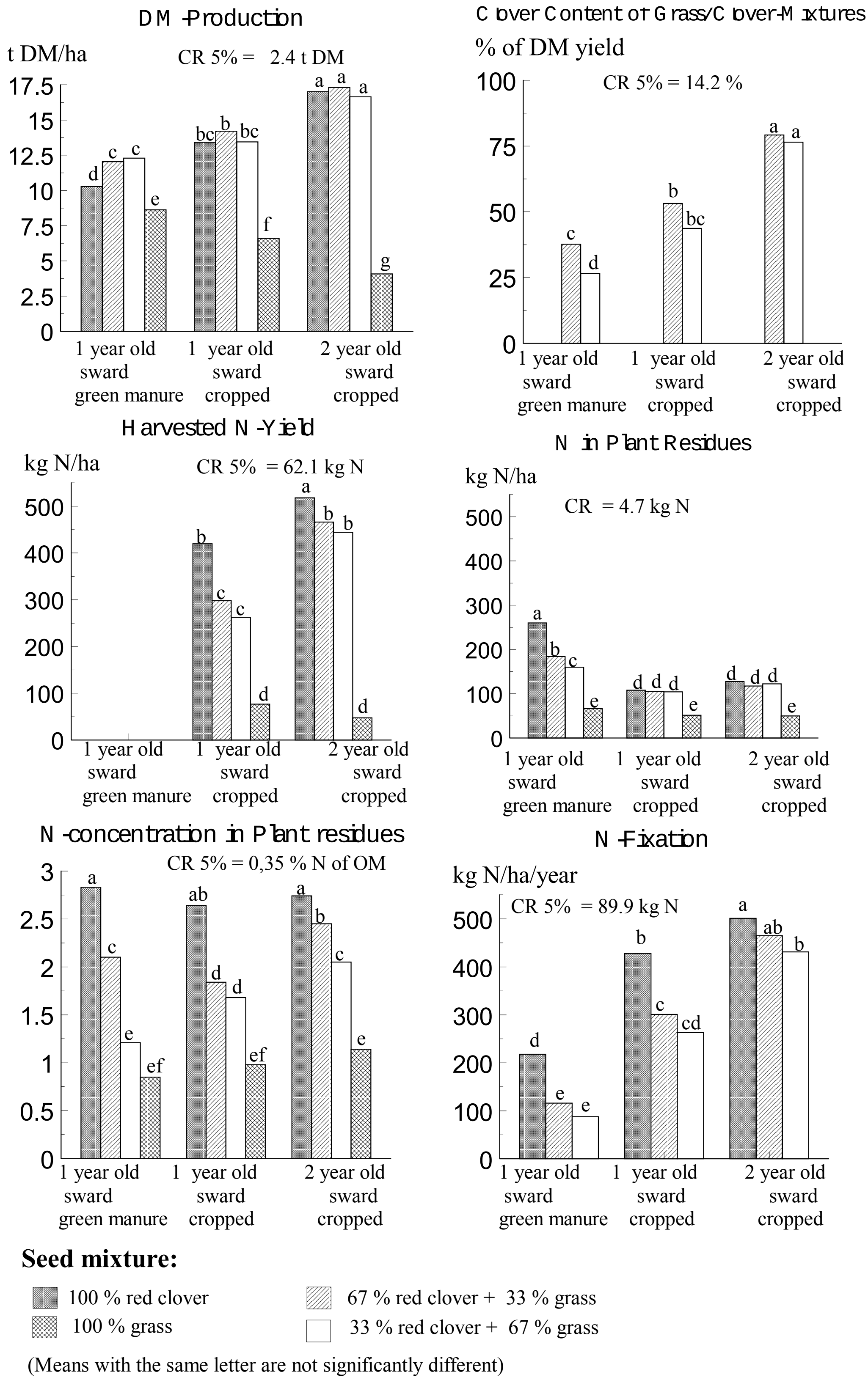


Figure 3 Effect of management of different red grass-clover seed mixtures on dry matter production, clover contend, harvested N-yield, N in plant residues, N-concentration in plant residues and N_2-fixation (Hohenschulen 1995).

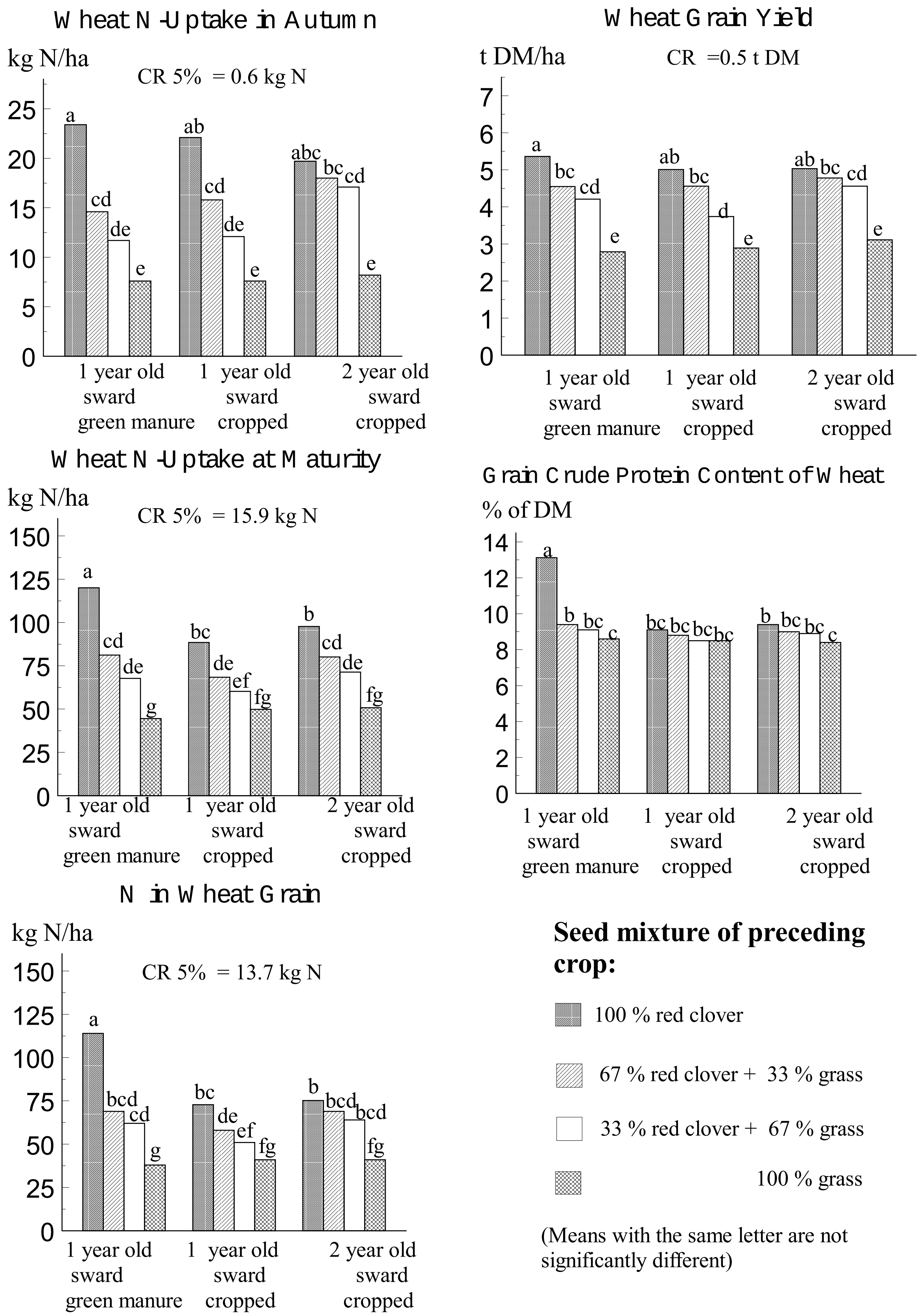


Figure 4 Effect of management and seed mixture of red clover grass on grain yield and grain crude protein content, grain N-amount and N-uptake at different stages of subsequent wheat (Hohenschulen 1996).

In experiment 2 all factors affected the considered variables significantly. The different variables influenced by various combinations of seed mixture and management are presented in Figure 3 and 4 as an average of the two considered companion grass species perennial and Italian ryegrass. Figure 3 shows that the dry matter production in 1995 was mainly affected by the management. Cropped swards with clover reached higher dry matter production than the mulched ones. Cropped leys with clover in production year two achieved higher dry matter and N-yields than the swards in the first production year. Contrary to the DM-yields of seed mixtures with clover, pure grass showed the highest DM-yields in the mulched system and the lowest DM-yields in year two of forage production. While in each of the two cropped systems there was no effect of the seed mixture on the DM-yields of swards with red clover, an increase of seed mixture clover content led to an increase of N-yields.

According to the residue N both experiments had comparable results. On average the mulched variants with clover in the seed mixture left approximately 200 kg N ha^{-1} as mulch, stubble and roots while comparable mixtures in the cropped systems left about 110 kg N ha^{-1} in crop residues on the field. While there was no difference in residue N between the different seed mixtures with clover in the cropped system, an increase of red clover content in the seed mixture led to an increase of the N amount in the not harvestable plant parts.

Figure 3 also shows the effect of seed mixture and management on the N-concentration in the not harvesteable plant parts. In this case the variation between 0.9 % of OM and 2.8 % of OM is mainly caused by the variation of red clover content in the seed mixture. An increase of seed mixture clover content led to an increase in nitrogen content.

All cropped swards with red clover in experiment 2 achieved higher clover contents in DM-yield and N-fixation than the mulched ones. With an average of more than 400 kg N ha^{-1} the cropped swards in the second growth period were more effective than both one year old swards. Clover contents in DM-yield of swards in the second production year were higher than in both one year old swards. In all sward types clover rich seed mixtures reached higher clover contents and N-fixation than seed mixtures with a lower clover content.

Figure 4 shows the influence of seed mixture and management of red clover/grass on grain yield, crude protein content and on nitrogen uptake at different stages of subsequent wheat. Clover content in the seed mixture accounted for most of the occurring variation of the variables considered in the subsequent wheat. A high seed mixture clover content led to high grain yields and also to a high N-uptake before winter as well as at maturity. An increased clover content in the seed mixture increased also the amounts of N that can be removed with the grain.

The mulched pure red clover sward with its very high amount of N in crop residues reached the highest grain yield, N-uptake and grain protein content in the subsequent winter wheat. Only the wheat following this sward achieved baking quality without additional fertilisation, but it is noteworthy that this economically desirable grain yield and quality only was achieved through an input of 260 kg N ha^{-1} in form of an incorporation of very lightly mineralisable plant material with an N-concentration of 2.8 % of OM which may lead to leaching losses of nitrogen. A comparison of clover content in DM-yield and the occurring variation of the variables considered indicates a correlation between clover content in DM-yield and N-yield, N_2-fixation, N-concentration in not harvesteable plant parts as well as grain-yield and N-uptake of the subsequent crop.

The results show that dry matter production, N-yield, residue nitrogen and N-fixation of legume/grass mixtures can be influenced by various combinations of legume species, seed mixture, management and duration of ley. The same factors also influenced grain yield, N-uptake and protein content of subsequent winter wheat. The named factors have to be considered when planning crop rotations.

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Importance of varying management and environmental conditions in a long-term crop rotation trial. Effects on plant development, crop yield and nitrogen dynamics

H. Schmidt[1] *and P. von Fragstein*[2]
[1]*Chair of Organic Farming, University of Giessen, Karl-Glöckner-Str. 21 C, 35394 Giessen, Germany*
[2]*Department of Ecological Agriculture, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany*

Summary

Annual variations in plant development and soil nutrient dynamics are governed largely by environmental conditions. To determine the level of variation and also the effect of specific climatic conditions have on crop yields, results of a long-term field trial at the University of Kassel, Germany, were statistically analysed. Results of a crop rotation trial, representing a stockless, organic farming system were examined. Results are presented for plant development, crop yield and N dynamics during 1992-1996. Each crop within the rotation, that is grass-clover (green manure), potatoes, winter wheat and spring barley was grown every year during the trial period. Biomass production and crop yields varied widely from one year to the next for all crops grown. The largest variation from the mean yield was found in spring barley at 61% and the lowest in winter wheat at 34%. The green manure crop and potatoes showed a larger variation in N uptake than in yields (dry matter) while the reverse was true for cereals. Soil mineral N measured in identical crops in consecutive years showed also a large variation of more than 50% of the mean. In some cases it was possible to attribute observed variation to specific environmental conditions. It was found that climatic conditions influence plant development and crop yield indirectly by affecting the disease pressure, the leaching of nitrate as well as the timeliness and type of soil tillage and cultivation.

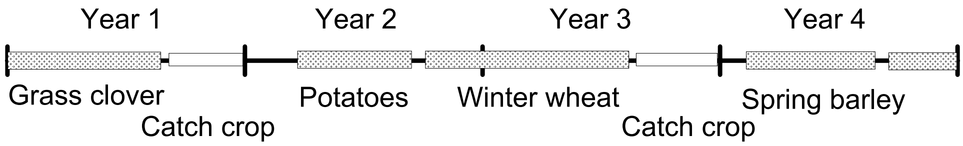
Introduction

The development of agricultural crops and soil nutrient dynamics can vary widely from one year to the next due to changing weather and environmental conditions. The annual variation is an important element in the overall assessment of crop rotations in long-term field trials. In linearly designed rotation trials which do not grow each crop every year, yield effects caused by weather and environmental conditions can only be detected after completion of several rotations. Rotation trials which are designed in such a way that each crop is grown every year during the trial period facilitate the statistical analysis of environmental effects on plant development and crop yield already after a relatively short trial period of only several years. However, the number of treatments is often low with this experimental design due to its high aerial and labour requirements. Nevertheless, linearly designed trials can be assessed also by using results detailing annual variations of various parallel rotation trials, provided the causes for annual variation such as weather conditions or management can be differentiated sufficiently.

This paper describes the annual variation in the development and nutritional status of agricultural crops based on results obtained from a long-term, non-linear rotation trial assessing a stockless organic farming system.

Materials and methods

A stockless, organic, four-year crop rotation has been tested since 1992 at the Neu-Eichenberg experimental farm (51°21'N, 9°52'E) of the Department of Ecological Agriculture at the University of Kassel (Figure 1). The data were collected between 1992 and 1996 (cash crops only from 1993 onwards). The part of the trial presented in this paper did not receive any fertiliser.



Rotation	1992	1993	1994	1995	1996
RI	Grass clover	Potatoes	Winter wheat	Spring barley	Clover grass
RII	Spring barley	Grass clover	Potatoes	Winter wheat	Spring barley
RIII	Winter wheat	Spring barley	Grass clover	Potatoes	Winter wheat
RIV	Potatoes	Winter wheat	Spring barley	Grass clover	Potatoes

Figure 1 Rotation scheme and plan of the four parallel cultivated rotations.

The trial was established as a randomised complete block design with four replicates and a plot area of 135 m^2, each. An identical crop rotation (grass-clover (green manure crop), potatoes, winter wheat, spring barley) was grown parallel in four rotations (RI – RIV), ensuring that each rotation grew a different crop in any given year (Figure 1). Oats were grown at the site in 1991 before the rotation trial was established. The trial was established on a loamy soil (13% clay, 83% silt and 3% sand), classified as loess derived Orthic Luvisol. The weather conditions at the site are shown in Figure 2.

Yields of green manure crops were determined by harvesting a 10-15 m² area per plot. The proportion of clover present was estimated. 10 plants per plot were sampled for above-ground and below-ground biomass of potatoes at the time of flowering, and tubers were sampled from 60 plants per plot for determination of the final potato yield. Cereal yields were determined by harvesting a 10-15 m² area per plot. The vegetative growth of catch crops was assessed by sampling four 0.15 m² areas per plot at the beginning of November. All harvested products were randomly sampled to determine dry matter (DM) levels (105°C) and N content (Heraeus Macro-N-Analyser).

Four soil samples per plot and per sampling date were taken to determine soil mineral N (N_{min}) at several dates per year. All N_{min} data relate to a soil depth of 0-90 cm, except for potatoes in Figure 3, which shows more detailed data. Soil samples were taken from all replicates of rotation I (RI) while only one replicate was sampled in the other rotations (RII, RIII and RIV). Samples were stored in the freezer before they were extracted with a 0.0125 molar calcium chloride solution (Thun *et al.*, 1991) and analysed for nitrate (NO_3^-) and ammonia (NH_4^+) with a Technicon Auto-Analyser. Crop yields were analysed statistically and means were compared using the multiple LSD test (Sachs, 1992). It was not possible to statistically analyse data related to N_{min} since only rotation I was sampled comprehensively. Consequently, relevant tables show only variations found in rotation I.

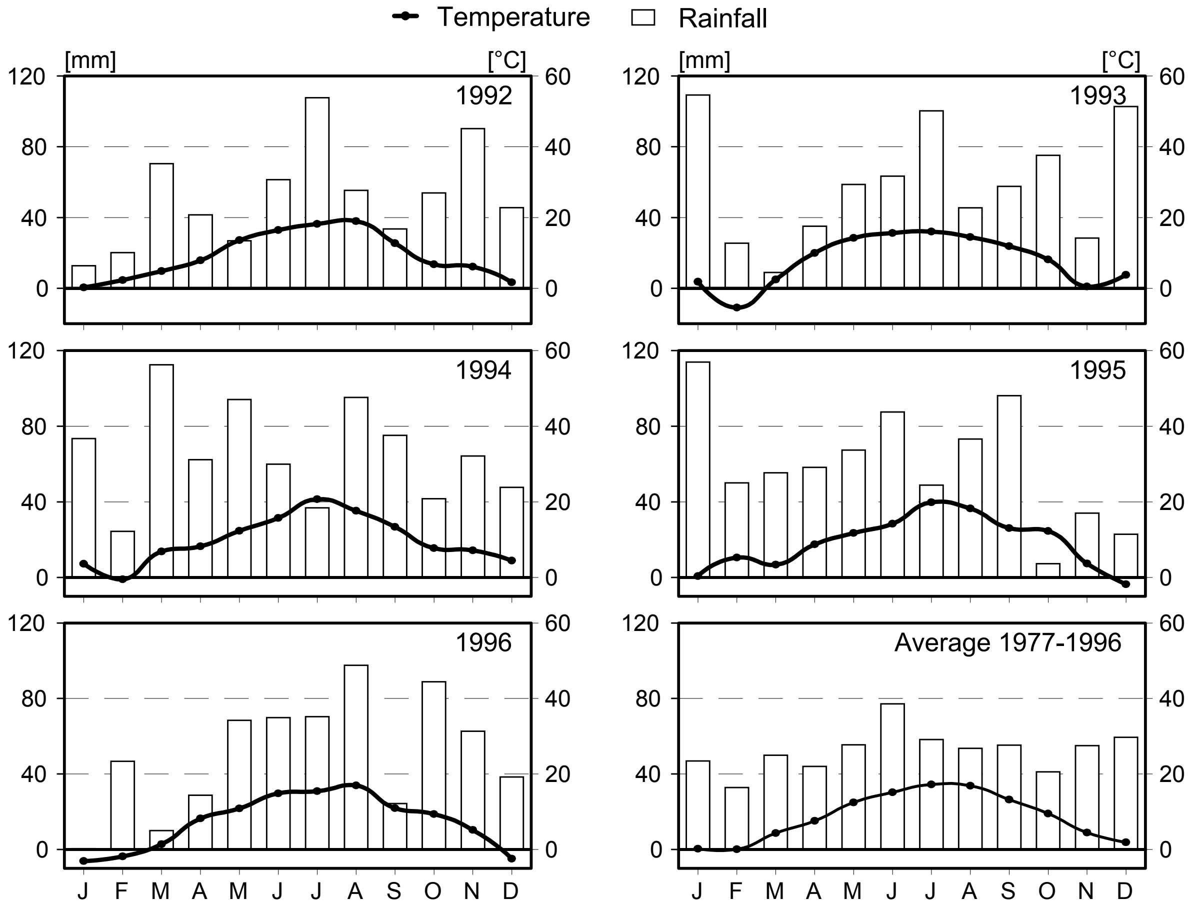


Figure 2 Monthly rainfall and average temperature at Neu Eichenberg between 1992 and 1996 and the long-term average.

Results and discussion

Grass-clover mixture (Green manure crop)

A one-year green manure crop consisting of a grass-clover mixture had to provide a sufficient N supply for the evaluated crop rotation. For this reason variations in biomass yield and N content, particularly of clover, are crucial for the whole rotation. Development of the green manure crop was affected by adverse weather conditions, pests and diseases as well as differences in management brought about by unfavourable weather conditions: (1) The scheduled under-sowing of spring barley with a mixture of grass and white clover was accomplished only once. In other years a mixture of grass and red clover or other clover species was sown only after barley was harvested. (2) The dates of sowing and ploughing varied over the years as well as the machinery used for cultivation (Table 1).

The amount of vegetative matter harvested over a three-year period varied between 74% and 133% of the mean yield, which amounted to 8.2 t DM ha^{-1}. The amount of N contained in the harvested grass-clover mixture showed an even wider variation with figures ranging between 51% and 170% of the mean (191 kg N ha^{-1}). Variations reported by other authors were of a similar magnitude (Junge & Marschner, 1991; Mietkowski & Horst, 1995; Stopes *et al.*, 1996). The proportion of clover in the mixture varied between 9% and 52% (DM basis) and the amount of N contained in clover plants varied even more widely with values between 20 and 225 kg N ha^{-1}.

Table 1 Shoot biomass, N-content and proportion of clover of grass-clover mixture (sum of the three mulching dates) and possible determining factors. Numbers in a row with identical letters are not significantly different at the 5% level.

	Rotation $_{Year}$					**Mean**
	RI_{92}	**RII_{93}**	**$RIII_{94}$**	**RIV_{95}**	**RI_{96}**	
Tillage	Plough	Cultivator	Underseed	Plough	Plough	
Seed date	06.09	12.08	28.04	16.08	25.08	
Clover	Red clover	Red clover	W. clover	Red clover	Mixture[a]	
Incorporation date	28.08	19.08	06.09	24.08	09.09	
Damage by			mice, draught	Fung. inf., draught		
Shoot (DM) (t ha^{-1})	10.9 a	9.5 b	6.1 d	6.9 cd	7.6 c	8.2
N_t shoot (kg ha^{-1})	322 a	208 b	157 c	97 d	170 c	191
Clover (% DM)	56 a	34 b	34 b	9 c	35 b	34
N_{clover} shoot (kg ha^{-1})	225 a	110 b	75 b	20 c	96 b	105

[a] Red and white clover and Swedish clover

The effect of sowing on the development of the green manure crop was demonstrated by the successfully undersowing the grass-clover mixture into the barley crop in 1994 ($RIII_{94}$). A lack of soil cultivation resulted in a high mouse population, which markedly reduced the number of white clover plants. However, the clover recovered remarkably well during the main growing phase. Rotation IV showed also a low clover content in 1995 (RIV_{95}) which was caused by an unidentified fungal disease. This was facilitated by relatively wet and mild conditions during November and December. The poor clover stand resulted in an insufficient N supply that may be the cause for a low biomass production of the grass-clover in this rotation. A direct impact of weather conditions on biomass production was observed in 1994 and 1995 ($RIII_{94}$ and RIV_{95}) when dry summer conditions limited yields. Early ploughing dates and the consequently shorter growing periods for the green manure crop are most likely the cause for lower biomass yields in 1993 (RII_{93}) and 1996 (RI_{96}) compared to 1992 (RI_{92}). No other elements were shown to have an impact on biomass yield or N accumulation of a grass-clover green manure crop.

In November, N_{min} levels in the soil were found to be low (average of 24 kg ha^{-1}) with very little variation over the years (Table 2). However, the analysis of the catch crop at the same time showed that it contained between 22 and 82 kg N ha^{-1}. This is an indication for a widely varying N mineralisation rate after ploughing the green manure crop in August. The rate of N mineralisation depends, among other factors, on the amount of N contained in the biomass ploughed under. In turn, this is governed by the N concentration found in the biomass as well as the clover content of the mixture. The relatively high accumulation of N in the green manure and catch crops in rotations I (RI_{93}) and II (RII_{94}) resulted in higher N_{min} levels in the following spring (Table 2).

Potatoes

Weather conditions influenced potato production directly as well as indirectly by having an effect on the type and timeliness of seed bed preparation, the subsequent quality of the seed bed, the timeliness of potato planting and the on-set and spreading of potato blight (*Phytophthora infestans*) which can have a major impact on the growing period of potatoes (Table 2).

Table 2 Yield and N-uptake of potatoes and possible determining factors. Numbers in a row with identical letters are not significantly different at the 5% level.

		Rotation $_{Year}$				Mean
		RI_{93}	RII_{94}	$RIII_{95}$	RIV_{96}	
Tillage		Plough	Cultivator	Plough	Plough	
Tillage date		16.02	10.05	03.05	02.04	
Growing period[a]	(days)	102	132	107	111	113
N_t previous grass clover	(kg ha^{-1})	322 a	208 b	157 c	97 d	196
N_t previous catch crop	(kg ha^{-1})	67 b	82 a	24 c	22 c	49
N_{min} previous November	(kg ha^{-1})	22	29	30	14	24
N_{min} March	(kg ha^{-1})	49	48	28	31	39
N_{min} harvesting	(kg ha^{-1})	57	17	44	32	38
N_t tubers	(kg ha^{-1})	118 a	105 a	53 b	60 b	84
Yield (DM)	(t ha^{-1})	8.4 a	8.4 a	4.4 c	5.4 b	6.6

[a] Days from planting until the date when 80% of tops had died.

Average potato yields amounted to 6.6 t DM ha^{-1} with yields ranging between 67% and 127% of the mean. N uptake of tubers on the other hand averaged 84 kg N ha^{-1} with a variation between 63% and 141% of the mean. Relatively short-term variations in weather conditions and N dynamics had, to a certain extent a profound impact on the development and N supply of potatoes. N_{min} dynamics and N uptake for potatoes are detailed in Figure 3. A direct effect of weather conditions on tuber yield was detected only in 1993 (RI_{93}). The unusually rapid development of the potato crop in that year was partly due to an uncommonly warm and dry spring (Krug & Wiese, 1972). Other factors, which strongly influenced plant development in potatoes, were the duration of the growing period and the nutrient supply. A high level of N_{min} in spring (March) resulted, both in 1993 (RI_{93}) and 1994 (RII_{94}) in the highest yield. The examined trial did not provide evidence to show that the duration of the growing period has an impact on potato yields (Table 2). However, a close examination of dynamics and up-take of N_{min} during the 1993 growing season (RI_{93}) revealed that the accomplishment of a high yield despite a relatively short growing period was mainly due to a high N uptake before flowering. This correlates to a high accumulation of N_{min} in early summer (Müller, 1984). In 1994 there was a slow N release, and the high yield in that year was predominantly due to the long growing period. Due to favourable weather conditions in 1994, *Phytophthora infestans* affected plants considerably later than in other years. Low accumulation rates of N_{min} in 1994 (RII_{94}) and 1995 ($RIII_{95}$) is probably due to late soil cultivation in spring caused by adverse weather conditions. Delayed spring cultivation results, on the one hand, in a lack of soil aeration and agitation facilitating N mineralisation (Harrach & Richter, 1992), and on the other hand in an undisrupted development of the weeds that may take up available N. The higher accumulation of N_{min} in 1993 (RI_{93}) compared to 1996 (RIV_{96}) can be due to both the earlier soil cultivation in 1993 and the higher N accumulation of the preceding green manure crop (Table 2). A comparison of the development of potato crops in 1993 and 1996 demonstrates the effect the green manure crop has on potato yields. A well developed green manure crop in RI_{93} resulted in considerably higher potato yields than in RIV_{96} when the green manure crop accumulated only very little N. This was despite similar environmental conditions in both years.

Winter wheat

Apart from the preceding crop, wheat production was directly affected mainly by weather conditions, but also by the intensity of soil cultivation, which was governed by weather conditions (Table 3).

N_{min} in autumn averaged 89 kg N ha^{-1}, which is a typically high level after potatoes (Baumann & Maass, 1957). No correlation was found between the annual variation of N levels and the assessed parameters. The amount of N_{min} which remained in the soil until spring was mainly controlled by the extent of nitrate leaching during the winter months. The amount of N_{min} increased during the dry winter of the RIV_{96} rotation while it decreased in all other rotations during winter due to much higher rainfall levels (Table 3). N_{min} was found to be low (< 40 kg ha^{-1}) during the main growing season. However, this is considered typical for winter wheat and confirms other research (Aichberger, 1982).

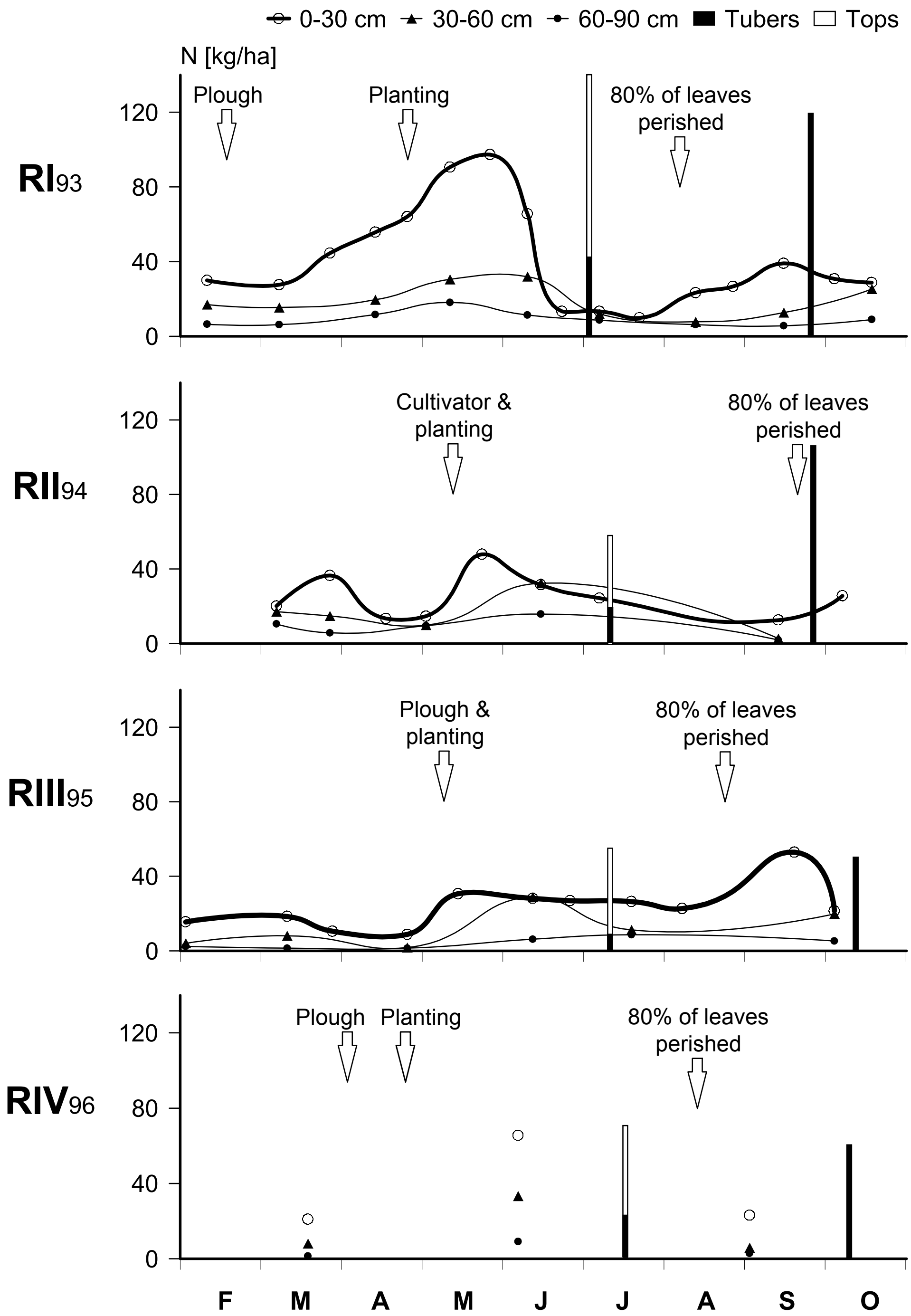


Figure 3 Nmin and N in potato tops and tubers in the different rotations between February and October.

Table 3 Yield and N-uptake of winter wheat and possible determining factors. Numbers in a row with identical letters are not significantly different at the 5% level.

		Rotation $_{Year}$				Mean
		RI_{94}	RII_{95}	$RIII_{96}$	RIV_{93} [a]	
Tillage		Rotary harrow	Plough	Plough	Plough	
Tillage date		28.10	14.10	24.10	16.10	
Growing period[b]	(days)	137	130	140	132	135
N_t previous grass clover	(kg ha^{-1})	322 a	208 b	157 c	-	
N_{min} previous November	(kg ha^{-1})	73	81	97	103	89
N_{min} March	(kg ha^{-1})	57	40	130	81	77
N_{min} harvesting	(kg ha^{-1})	16	17	28	21	21
N_t grain	(kg ha^{-1})	69 bc	56 c	99 a	80 ab	76
Yield (DM)	(t ha^{-1})	3.6 bc	2.9 c	5.5 a	4.6 ab	4.1

[a] Without set-aside before.
[b] Days from 01.03 until harvesting above a temperature of 5°C.

Between 1993 and 1996 wheat yields averaged 4.2 t DM ha^{-1} with yields ranging between 71% and 134% of the mean. N uptake of wheat on the other hand averaged 76 kg N ha^{-1} with a variation between 74% and 130% of the mean. Both a more facilitating N supply as well as more favourable weather conditions contributed to increased yield levels in 1993 (RI_{93}) and 1996 (RIV_{96}). The appropriate N supply in both rotations can be attributed mainly to the accumulation of N_{min} in the previous year after aboveground potato plants died, and also to the level of nitrate leaching during winter (Table 3). A cool and moist summer, as observed in 1993 and 1996, is considered to be very favourable for wheat production (Otter, 1982). On the contrary, a dry and hot summer, as experienced in 1994 (RI_{94}) and 1995 (RII_{95}) is seen as less advantageous for wheat production (Gusta & Chen, 1987). A comparison of the presented results with those obtained in state-wide (Hessen) trials conducted during the same period show identical variations and hence demonstrate the effect of weather conditions on wheat yields (Table 4). No other parameter was shown to have a significant impact on wheat yields.

Table 4 Average yield of organic grown winter wheat at different locations in Hessen (Völkel, 1997) and own results between 1993 and 1996 (t DM ha-1).

	1993	1994	1995	1996	Mean
Own results	4.6	3.6	2.9	5.5	4.1
Average	6.1	4.6	4.5	6.4	5.6

Both, N_{min} and the amount of N found in the catch crop grown after winter wheat were on a low level in November and did not vary greatly during the trial period (Table 5). Low N availability at this stage of the crop rotation is caused by a high N uptake of wheat and also by N immobilisation due to the incorporation of straw. These effects override any other factors potentially affecting soil N levels. It was not possible to determine what caused N_{min} levels to vary between 17 and 34 kg ha^{-1} in March.

Table 5 Yield and N-uptake of spring barley and possible determining factors. Numbers in a row with identical letters are not significantly different at the 5% level.

		Rotation $_{Year}$				Mean
		RI_{95}	RII_{96}	$RIII_{93}$[a]	RIV_{94}[a]	
Tillage		Plough	Plough	Plough	Cultivator	
Tillage date		14.03	02.04	16.02	28.04	
Growing period[b]	(days)	107	133	124	103	117
N_t previous grass clover	(kg ha^{-1})	322 a	208 b	-	-	
N_t previous catch crop	(kg ha^{-1})	23 a	23 a	27 a	25 a	25
N_{min} previous November	(kg ha^{-1})	10	10	14	12	27
N_{min} March	(kg ha^{-1})	17	22	34	34	27
N_{min} harvesting	(kg ha^{-1})	16	18	23	36	23
N_t grain	(kg ha^{-1})	30 c	49 a	35 b	23 d	34
Yield (DM)	(t ha^{-1})	1.7 c	3.7 a	2.7 b	1.3 d	2.3

[a] Without set-aside before.
[b] Days from seed until harvesting.

Spring barley

Production of spring barley was affected by weather conditions and varied with regard to the kind and time of tillage as well as the date of sowing, which is mainly responsible for variations in the growing period of barley crops.

Barley yields averaged 2.3 t DM ha^{-1} with yields ranging between 57% and 161% of the mean. N uptake of barley on the other hand averaged 34 kg ha^{-1} with a variation between 68% and 144% of the mean. Apart from slight variations in the supply of N, it became obvious that positive yield effect were mainly caused by a prolonged growing period (Table 5). Farack (1996) also found such a close correlation between the date of sowing and the development of spring barley. Apart from the delayed sowing of barley in 1994 (RIV_{94}), plant development was further hampered directly by the insufficient preparation of the seed bed. This resulted in a high density of weeds, which reduced yields indirectly. It was not possible to show that the cropping sequence or weather conditions have a direct impact on the yield of spring barley.

Results obtained in state-wide (Hessen) trials conducted during the same period show that the overall annual weather conditions have an overriding direct and indirect influence on the yield of spring barley. Sander (1997) confirms presented results by reporting that barley yields were approximately twice as high in 1996 (5.6 t ha^{-1}) as those obtained in 1995 (2.5 t ha^{-1}).

Conclusion

Presented results show that annually varying weather conditions have an overriding effect on biomass production and crop yields as well as on N supply in a stockless, organic farming system. Another long-term trial which assessed crop rotations for an organic, stockless farming system resulted in similarly high yield variations (Stopes *et al.*, 1996). Simon & Werner (1963) and Wrankmore (1990) also reported the overriding effect of environmental conditions on crop yields. On the basis of long-term trials, Wrankmore (1990) demonstrated that 70% of variance of crop yields was caused by varying weather conditions while only 2% of yield variance was caused by different preceding crops (comparison of cash crops with fodder legumes). This is confirmed by our results, which showed that preceding crops had very little effect on the yield of wheat and barley. Plant and yield development of these crops was hardly influenced by a preceding green manure crop.

The effect of different environmental conditions on plant development and yield varied greatly among the tested crops and the various elements could rarely be differentiated properly. However, the presented results suggest that yield levels were affected by weather conditions mainly in an indirect way, namely through the kind and timeliness of soil cultivation, the disease pressure and the level of nitrate leaching. The high water holding capacity of the soil at the trial site (loess) might have prevented rainfall from having a direct impact on yield levels.

A lot more data are required to fully ascertain the mentioned mechanisms affecting yield levels. This can be achieved either by extending the duration of long-term trials or by statistically analysing a range of results obtained in similar trials at various other locations.

Acknowledgement

The trial was during 1994 to 1996 part of an EU-funded collaborative research project under contract R3-CT93-0852.

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External N sources in an organic stockless crop rotation - useful or useless additives?

P. von Fragstein[1] *and H. Schmidt*[2]
[1] *Department of Ecological Agriculture, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany*
[2] *Chair of Organic Farming, University of Giessen, Karl-Glöckner-Str. 21 C, 35394 Giessen, Germany*

Summary

A rotational field trial *'Stockless organic crop rotation'* was initiated in 1991 at the research farm of the University of Kassel, containing one set-aside and three saleable main crops: (1) clover grass, (2) potatoes, (3) winter wheat, (4) spring barley. Four treatments were included: (A) unamended control, (B) source separated compost, (C) sugar beet vinasse, (D) a combination of (B) and (C). Only the cereals were fertilised by different dosages: (B) 100 kg N ha^{-1} to winter wheat and 60 kg N ha^{-1} to spring barley, (C) 60 kg N ha^{-1} to winter wheat and 40 kg N ha^{-1} to the catch crop preceding spring barley, (D) combination of (B) and (C).

- The applied source separated compost (160 kg N ha^{-1}, 11 t dm ha^{-1}) was found as a very low quality N source. Only 6% of the total nitrogen was taken up by the grains. The increase of yield was approximately 5.7 dt ha^{-1}.
- Of the applied sugar beet vinasse-N 21% were used by the grains of winter wheat and spring barley. The cereals responded by significant increases of the grain yield (3.7 dt ha^{-1} (WW) and 4.3 dt ha^{-1} (SB)) and the protein content (+0.4% (WW)).
- The combination of both fertilisers caused the highest levels of yield and N uptake by the cereals.

Introduction

In response to the EU-Extensification programme and the substantial increase of organic farming in the EU (Fragstein *et al.,* 1997) the ideal mixed system of organic farms is tending to be replaced by systems of low or no stocking. The management of crop rotation and nutrient provision has to be rethought and, if necessary, adopted to the changed conditions of farms. As part of a rotational trial (Schmidt & Fragstein, 1999) off-farm N-sources have been assessed for their fertilising efficiency in cereals.

Materials and methods

Since 1992 a rotational field trial has been conducted at the Research farm Neu-Eichenberg of the University of Kassel. The main questions of the project are (a) the potential of an annual leguminous green fallow with regard to soil fertility, nutrient provision, and weed regulation, (b) the effect of applied off-farm N-sources on crop yield, yield components and quality. The trial was established on a parabrown soil, in a randomised block design with 4 replicates. Due to the cultivation of all crops in one year the trial can be assessed horizontally on a year's level and vertically on a rotational level. The lay-out of the plots (9 m × 15 m = 135 m²) was suited for normal agricultural mechanical tools. The rotation consists of four main and two cover crops (Table 1). The grass-clover was mulched twice to three times depending on climatic conditions. Of the succeeding main crops the cereals winter wheat and spring barley were fertilised by source separated compost, sugar beet vinasse or a mixture of both (Figure 1 and Table 2).

Table 1 Ecological stockless rotation.

Rotation	1993	1994	1995	1996
R I	Potato	Winter wheat	Spring barley	Grass-clover
R II	Grass-clover	Potato	Winter wheat	Spring barley
R III	Spring barley	Grass-clover	Potato	Winter wheat
R IV	Winter wheat	Spring barley	Grass-clover	Potato

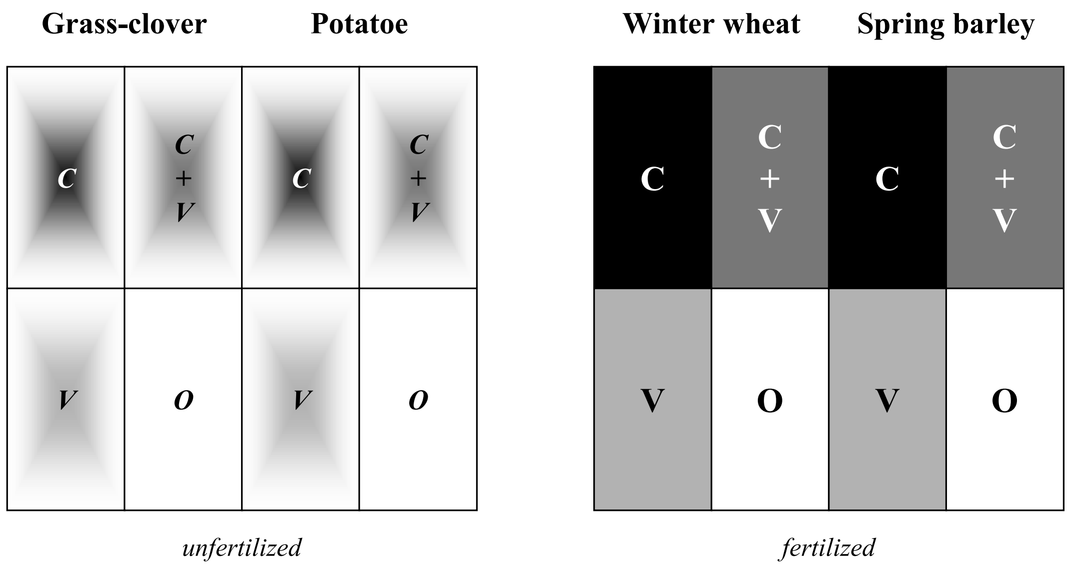

Figure 1 Experimental design of rotational field trial 'Ecological stockless rotation' (1 of 4 replicates) (The fertiliser treatments are shown in Table 2).

Table 2 Fertiliser treatments in the rotational field trial 'ecological stockless rotation'.

		Winter wheat	Spring barley	N-input
		kg N ha^{-1}		kg N ha^{-1} yr^{-1}
O	Control	0	0	0
C	Compost	100	60	40
V	Vinasse	60	40	25
C+V	Compost + vinasse	160	100	65

The fertilisation of vinasse was concentrated on the third year of the rotation: A) in spring (60 kg N ha^{-1}) to the growing stand of winter wheat (stage: EC 25-31), B) in late summer (40 kg N ha^{-1}) to the stubbles and straw of the same crop.

Compost was applied within the rotation at two dates: A) 100 kg N_{total} ha^{-1} (5.5 - 7.1 t DM ha^{-1}) to winter wheat in spring (stage: EC 25-31), B) 60 kg N_{total} ha^{-1} (3.3 - 4.3 t DM ha^{-1}) to spring barley shortly before sowing, including a shallow incorporation into the soil.

Methods for the analyses of nutrients are described by Schmidt (1997).

Results

Winter wheat

The yield of total biomass - averaged over three rotations - was increased, but not significantly affected by the fertilisation, whereas the grain yield could be significantly differentiated from the control (+8% and +11%) when vinasse was applied (Table 3). Of the three yield components (ears m^{-2}, grains/ear, TGW) only grains/ear were significantly increased by all types of fertilisation.

The grain protein content increased significantly when vinasse was applied (single: +0.4%; combined: +0.8%). The nutrient content of the grains was hardly affected by the fertilisation except the N content. When related to the grain yield the uptake of nutrients could be significantly differentiated between control and vinasse for N and Mg, between control and combined fertilisation of vinasse and compost for all nutrients (Table 4).

Table 3 Yield and quality parameters of winter wheat (average of 1993 to 1996). Numbers in a row with identical letters are not significantly different at the 5% level.

		Treatments							
Parameter	Unit	0		C		V		C+V	
Grain yield	dt ha^{-1} (86% dm)	48.1	b	51.3	ab	54.0	a	55.2	a
Ears m^{-2}		399		356		367		371	
Grains/ear		22.9	c	23.9	b	24.6	ab	25.6	a
TGW	g (dm)	45.0		45.3		44.8		44.3	
Protein	% (dm)	10.5	c	10.6	bc	10.9	b	11.2	a

Table 4 Nutrient export (kg ha^{-1}) by grains of winter wheat (average of 1993 to 1996). Numbers in a row with identical letters are not significantly different at the 5% level.

	Treatments			
Parameter	0	C	V	C+V
N	75.9 c	81.7 bc	88.0 ab	93.3 a
K	17.4 b	17.9 b	19.1 ab	19.5 a
P	15.4 b	16.3 ab	17.3 ab	17.7 a
Mg	7.8 b	5.1 ab	5.4 a	5.5 a

Spring barley

The spring barley yields were rather low during 1994 to 1996, ranging from 25.8 dt ha^{-1} to 30.7 dt ha^{-1} in grain yield (Table 5). Although vinasse was applied to the preceding catch crop it caused significant increases for all yield parameters (grain, straw and total biomass); this is also true for the effect of the single compost amendment on grain yield and total biomass. Of the three yield component parameters only the TGW achieved significant increases between the control and the treatments with vinasse.

Table 5 Yield and quality parameters of spring barley (average of 1993 to 1996). Numbers in a row with identical letters are not significantly different at the 5% level.

Parameter	Unit	Treatments			
		0	C	V	C+V
Grain yield	dt ha^{-1} (86% dm)	27.1 c	29.6 b	31.3 b	33.3 a
Ears m^{-2}		452	484	503	508
Grains/ear		11.8	12.0	12.1	12.2
TGW	g (dm)	42.4 c	42.8 bc	43.7 ab	44.2 a
Protein	% (dm)	9.6 b	9.7 b	9.8 b	10.0 a

The protein content was slightly, but significantly increased when both compost and vinasse were applied. Analogously to the result of winter wheat the fertilisation had only minor influence on the content of all nutrients apart from N (protein). But because of the yield increase all treatments caused significantly higher nutrients export compared to the control (Table 6).

Table 6 Nutrient export by grains of spring barley (average of 1993 to 1996). Numbers in a row with identical letters are not significantly different at the 5% level.

	Treatments			
Parameter	0	C	V	C+V
N	34.1 c	37.8 b	40.4 b	43.3 a
K	13.7 c	14.9 b	15.6 ab	16.5 a
P	10.0 c	10.9 b	11.4 ab	12.1 a
Mg	2.8 c	3.1 b	3.2 b	3.5 a

Table 7 N balance of the cereals related to the control.

		Treatments		
	Unit	C	V	C+V
N-input	kg N ha^{-1}	160	100	260
NH_4-N-, NO_3-N-input	kg N ha^{-1}	9.0	6.5	14.6
N-output (## - control)	kg N ha^{-1}	10.0	21.2	30.4
N-efficiency	% O/I	6.3	21.2	11.7

Balance

The N balance of the different fertilisation schemes clearly show the different character of the two fertilisers (Table 7). Compost only released 6% of its N input whereas 21% of vinasse-N was found in the grains of the cereals. The combination of both fertilisers almost achieved an additive output of the single treatments, which equals 12% of its N input.

Nutrient balance of the crop rotation

In order to enable a comparison of the inputs and outputs of nutrients over the entire crop rotation the averaged data of the rotations from 1993 until 1996 are compiled in Table 8. Within that period each crop was grown and each fertiliser was used. The combined fertilisation achieved a surplus of nutrients in the system. All other treatments resulted in negative balances, i.e. larger outputs than inputs. It has to be considered that this compilation was made without the N-input through nitrogen fixation in legumes.

Of the measured soil parameters the content of available potassium and the pH value were distinctly influenced by the application of vinasse (K content) or compost (pH value) (Table 9). Whereas the control showed a K-deficit between initial and final analysis the K input through vinasse and compost was reflected in continual increase of the differences resulting in positive balances for the treatments that included vinasse. The pH value slightly diminished between 1992 and 1996; the decrease was significantly less when compost was applied. P and Mg did not respond to the treatments.

There was no significant influence of the fertilisation on the total content of K, P and Mg (measured in 1992 and 1995). The same is true for total N in the soil (Table 10). The application of compost, however, caused significant increases of the initial values of C total, therefore a gradual enrichment of soil organic matter can be observed.

Table 8 N balance (kg N ha^{-1}) of saleable crops in response to different treatments (average of the years 1993-1996). Numbers in a row with identical letters are not significantly different at the 5% level.

		Treatments			
Parameter		0	C	V	C+V
N	Input	0	160	100	260
N	Export	194 c	201 bc	209 b	223 a
N	Input - Export	-194 d	-41 b	-109 c	37 a

Table 9 Soil status of available nutrients and pH (Difference of rotational means from 1996 and 1992). Numbers in a row with identical letters are not significantly different at the 5% level.

		Treatments							
Parameter	Unit	0		C		V		C+V	
K	mg kg^{-1}	-13.0	c	-4.2	bc	2.1	b	15.6	a
P	mg kg^{-1}	-26.2	a	-25.4	a	-25.9	a	-22.7	a
Mg	mg kg^{-1}	-25.0	a	-23.1	a	-22.5	a	-24.4	a
pH		-0.14	b	-0.04	a	-0.12	b	-0.04	a

Table 10 Changes of total C and N in the soil (average of the rotations in 1992 and 1995). Numbers in a row with identical letters are not significantly different at the 5% level.

		Treatments			
Parameter	**Unit**	**0**	**C**	**V**	**C+V**
C_t	% of C_{92}	1.4 b	4.1 a	1.6 b	5.6 a
N_t	% of N_{92}	-5.2 a	-3.6 a	-4.7 a	-2.8 a

Discussion

The different fertiliser treatments were included into the rotation in order to investigate the effects of the application of compost, vinasse or a combination of both would suit two soil and plant aspects: A) maintenance and increase of soil fertility, B) short-term plant nutrition. The discussion will primarily cover the short-term effect of fertilisations and secondary summarise conclusions, which will take into account expectations for long-term effects.

Short-term effects of compost amendments

Soil processes and plant development can be greatly influenced by the application of composts (Dick & McCoy, 1993). Due to the relatively short trial period and low dosages of composts, marked changes of soil properties beside short-term fertilising effects could not be expected. This was confirmed by the very small (although significant) influence on the pH value and soil organic matter content. Here only the nutritional effects of compost fertilisation will be emphasised.

The compost application to winter wheat did not cause significantly increased exports of N, P, K and Mg. The N efficiency of source separated composts can range from -1 to 25% (Döhler, 1995). According to Vandré (1995) the N availability of composts is less than 10%. Referred to the own data the N release to winter wheat could not have exceeded 10 kg N ha^{-1}. The high nutrient status of the soil caused a lower efficiency of the compost for crop yield (Petersen *et al.*, 1996). The same is true for the other nutrients, although more available than N, their influence on the nutrient uptake was also masked by the high soil fertility (Vogtmann *et al.*, 1991).

Spring barley after winter wheat could have responded to application of compost to both the precrop and to the same crop. The positive influence on grain yield and nutrient exports could be statistically differentiated. The latter ones increased by 10 to 13% over the untreated control. The increase of N-export was distinctly smaller than the described figure of 10% of N-efficiency of applied composts. Therefore residual effects of the precrop amendments could not be clearly distinguished. The experimental design did not allow the positive effect on grain yield (+3.7 dt ha^{-1}, +11%) and nutrient export to be differentiated between compost-N and other nutrients/factors.

The increase in total N-export through winter wheat and spring barley yielded 10 kg N ha^{-1} which corresponded approximately 6% of the imported compost-N, which is in the lower end of cited N-efficiencies (Döhler, 1995). These figures reflect the amount of measured N_{min} of the composts, which relates to short-term plant nutrition effects (Fragstein *et al.*, 1995).

In some cases the cereal plots were not only fertilised to these crops, but also to previous cereals being grown on the same place. These applications were done at least three years ago, but had no long-lasting effect on the yield parameters. This was also true for the crops directly succeeding the cereals; grass-clover and potatoes.

The short-term effect of source separated composts can be graded as very small. Quick responses of plant growth to compost application cannot be expected on soils of a high fertility (Vogtmann *et al.*, 1991; Poletschny, 1992; Asche & Steffens, 1995).

Short-term effects of vinasse applications

Analogously to compost, vinasse can show various interactions with soil and plants. Debruck & Lewicki (1990a) emphasized the positive effects of quickly available nitrogen and potassium for plant nutrition and the increased microbial activity due to easily degradable carbohydrates.

The grain yield was distinctly increased by the first application of vinasse (mainly influenced by higher grains/ear-ratios); this was also true for the N and protein content. There was no effect on the contents of P, K and Mg. The fertilisation with vinasse could mainly be graded as a N effect based on higher N mineralisation and higher N-exports (+13%) through the grains. A specific priming effect of vinasse to the mineralisation of the soil could not be excluded and seemed very propable due to the microbial responses after vinasse amendments. Debruck & Lewicki (1990b) referred to an N efficiency of 50 to 60% within the first year of application. These figures could not be confirmed by the actual data, averaged 17% increase of the N-export. But the achieved yield increase of 3.7 dt ha^{-1} (8%) and the improvement of quality by higher protein levels (+0.4% points) were quite relevant.

The missing effect of added potassium indicates that the soil's native K supply was sufficient despite its low grading (HLVA, 1989).

Both applications of vinasse to the third part of the rotation caused clear increases in grain yields by the succeeding spring barley. The increase in yield was 4.3 dt ha^{-1} (17%) and was higher than for winter wheat. Contrasting to winter wheat the protein content did not respond to the fertilisation; a positive fact for the use of malting barley. The nutrient content of the grains was also unaffected by the treatments. The export of nutrients however exceeded the untreated control by 15 to 21% due to higher yields. The experimental design did not allow the effect of increased available N and other nutrient factors (mainly potassium) as yield increasing factors to be distinguished.

In summary the increase of N-export by the cereals corresponded to 21% of the imported vinasse-N. The two-year perspective of N efficiency was far below the figures of Debruck & Lewicki (1990a).

In some cases winter wheat plots were components of two rotational courses. Therefore they were fertilised with vinasse more than twice. These fertilisations were at least 3 years ago. They had no further effect on wheat yields. Similar lack of responses could be observed when grass-clover (2 year after last application) and potatoes (3 years) were grown.

Vinasse was found to be a rather N-efficient organic fertiliser. Although expectations of its effectiveness could not be entirely fulfilled its application for short-term manipulation of N provision of plants was more useful than that of compost. Increases of grain yield and quality parameters, i.e. protein content were achieved.

Short term effects of combined applications of compost and vinasse

The effects of the combined treatment of both fertilisers were essentially a sum of the effects found for the individual treatments, synergistic effects were not found. The effect on yield level and N-exports of the cereals were mostly significantly different to the untreated control, but could not be distinguished from the single components of fertilisation to the same extent. The sum of exported N of both cereals, however, was significantly higher than all other treatments. Again its level was nearly the sum of both individual components.

In one case a longer lasting effect of the combined fertilisations could be found two years after the last application: potatoes (not fertilised) achieved significant yield increases in these plots.

Conclusions

Under the perspective of sustainability the existing crop rotation has a need for further N-inputs apart from green manure crops. The concept of nutrient recycling is very well realised by the use of organic fertilisers and the automatic inputs of other nutrients. In stockless systems source separated composts are suitable for the compensation of nutrient balances and the long-term improvement of soil organic matter. Vinasse suits for the input of N and K and makes possible a direct manipulation of plant growth due to its high availability of N. The combination of both fertilisers seems to be useful depending on different targets and circumstances. Due to the good soil status of the experimental site the continuous use of the combined fertilisers can provoke luxurious accumulations of nutrients.

From the agronomic point of view the application of the tested off-farm N-sources appears useful and adequate for the requirement of additional C- and N-input in stockless organic systems. Considering the changing estimates for purchasable soil conditioners and fertilisers and the predictable exclusion of source separated composts from Annex I of the EU-directive 2092/91 there is an urgent need for the elaboration of valuable (and applicable) concepts for organic farming systems in future; either by co-operative approaches among organic farms of differing structure or by the improved recycling of valid organic sources. Contaminated residues of genetically modified crops as part of organic fertilisers might provoke principal considerations about the use of purchasable fertilisers of mainly conventional origin.

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Strategies to avoid nitrate leaching after potato crops by applying different cultivation methods to the following cereals

H.J. Reents[1] and K. Möller[2]
[1] Co-ordinator for ecological agriculture and horticulture,
Technical University Munich-Weihenstephan, D-85350 Freising, Germany
[2] Chair of phytopathology,
Technical University Munich-Weihenstephan, D-85350 Freising, Germany

Summary

Observations of high nitrate levels in soil after the harvesting of potatoes were the starting point of the project. Therefore different cultivation methods were tested with regard to prevention of nitrate leaching to groundwater and to N-uptake in plant biomass: the effect of different cereals, the date of sowing of winter cereals, the intercropping of winter cereals with white clover and mustard seed catch crops and the combination of mustard catch crops with following spring wheat in comparison to winter fallow.

The results showed no differences between winter cereals but distinct effects of the cultivation methods on nitrate leaching during winter. Early sowings (mid September) especially when intercropped with white clover reduced nitrate leaching to a level equal to that of a mustard catch crop. The yields of early sowings were almost as high as for October-sowings but the kernel quality was slightly reduced. Intercropping with white clover decreased the yield and the kernel quality of winter rye and winter wheat but not spelt. The effects of a mustard catch crop were lower yields and kernel quality of winter wheat as well as of spring wheat.

Introduction

Over the last few years the risks of nitrate leaching in autumn after ploughing up legumes have often been discussed (Brandhuber & Hege, 1992; Heß, 1989; Heß *et al.*, 1992; Reents, 1991; Stopes *et al.*, 1992). During the growing period, the fodder legumes enrich the soils with N-rich organic matter, which is mineralised after tillage. Depending on the local conditions of soils and the weather, nitrate may pose a risk for groundwater and at the same time a loss from the farm N-reserve.

In addition to the above there are other periods in many crop rotations in which similar risks may arise. After harvesting potatoes the nitrate content in soils increases significantly as already reported (Alföldi *et al.*, 1992; Paffrath, 1993; Stein-Bachinger, 1993; Wistinghausen, 1984). One of the reasons may be stubble and root residues of the previous fodder legumes and organic fertilisers. At the beginning of the potato cultivation intensive tillage and weeding stimulates the mineralisation of organic matter. After the ripening period the organic substances in the soil seem to become stabilised. As a result of soil desturbance and aeration during harvesting, another period of mineralisation of organic matter starts which leads to a rapid increase of nitrates in the soil.

As a rule potatoes are harvested from mid to end of September in southern Germany and the conditions for mineralisation are normally very good. Since harvesting begins fairly early, the critical period in which nitrate is formed is particularly long. We therefore assume that winter wheat cultivated under usual conditions (sowing mid October) cannot take up nitrate from the soil to a sufficient extent.

With regard to the problems of crop rotations the research aimed at clarifying the following questions: How do different cultivation strategies for grain and catch crops influence nitrate dynamics in soil after the harvesting of potatoes and what are the main effects on growth and yields of the following grains?

Materials and methods

During the period from 1994 to 1997 a field trial was carried out on the organically cultivated fields at the experimental station Klostergut Scheyern of the Technical University Munich-Weihenstephan. The experimental station is located in south Bavaria, 40 km north of Munich and 480 m above sea level. The annual mean temperature at the site is 7.8°C, and the rainfall is 830 mm yr^{-1}. The soils on the station are Luvic Cambisols, Luvisols and Kolluvisols with soil texture varying from loamy sand to silty loam.

The following treatments were carried out (Table 1):
1. three different sowing dates of winter cereal
2. sowing winter cereals in October into a standing mustard seed catch crop, which had been sown in September
3. intercropping of winter cereals with white clover both sown in September
4. mustard seed catch crop and fallow, both followed by spring wheat

Table 1 Experimental treatments.

Treatment	Wheat[1]	Winter rye (WR)	Spelt (Sp)
September seed	Bussard (WW)	Motto	Rouquin
October seed	"	"	"
November seed	"	"	"
Sept + white clover (WC)	"	"	"
mustard + Oct seed winter cereals	"	"	"
mustard + spring wheat	Nandu (SW)		
fallow + spring wheat	"		

[1] 1994/95 only wheat (without white clover)

The layout of the field trial was based on a split-plot design with four replicates covering a plot area of 3 × 10 m.

In 1994 after the harvesting of potatoes the field was ploughed, but in 1995 and 1996 the soil was only loosened. The cereals were sown by using a combination of a rotary harrow and drilling machine at the following seed rates: winter wheat 190 kg ha^{-1} (September reduced to 140 kg ha^{-1}), spring wheat 210 kg ha^{-1}, spelt 185 kg ha^{-1} and winter rye 140 kg ha^{-1}.

In the first year soil samples were taken every four weeks after the sowing date until grain harvest from a depth of 0-90 cm divided into layers of 30 cm. In subsequent years soil samples were taken only in October, December, April and August, with the last samples taken to a depth of 150 cm. The soil samples were extracted with distilled water at a ratio of 1:2. The nitrate content was measured with a SKALAR-Analyser.

The winter 1994/95 was characterised by temperatures above the long-term average. There was only a short frost period, which lasted from the end of December until mid January. Otherwise winter temperatures remained above the freezing point and rose to 10°C on some days. In comparison to the first year the 1995/96 winter had a long period of frost from the end of November until the end of March. Precipitation was low and the springtime was also predominantly dry. Autumn 1996 was characterised by a lot of rain and the soils became water-saturated. However the winter was extremely dry again and cold.

Results

Nitrate dynamics in winter and spring time

As a principal example for all the years Figure 1 shows the effects of different treatments on nitrate dynamics in 0-90 cm of soil from October until the harvest in August 1995. In November maximum levels of nitrate were found in the fallow treatment and in the October and November sowings. Low levels were detected in treatments with mustard catch crop and the early sown winter wheat (ww-Sep). The subsequent development of the nitrate content in soil was the result of the relationship between plant growth and weather. Thus the lowest amounts of nitrate were found in catch crop treatments in December. Nitrate contents in ww-Nov, fallow and ww-Oct were still high (70 kg NO_3-N ha^{-1}) but nitrate had leached from topsoil into deeper layers (30-90 cm). The favourable development of the catch crop reduced nitrate leaching.

As a result of the warm weather in the winter of 1994/95 the mineralisation of catch crops after break down started as early as February and nitrate content in soil increased (Figure 1). In the period from December to April more nitrate leaching occurred down to soil depths lower than 90 cm in treatments where the wheat plants covered the soil to a low extent (ww-Oct, ww-Nov). The early sowing of wheat prevented nitrate leaching but at the same time the nitrate available to plants (0-90 cm) was very low (Figure 1). At the beginning of the growing season nitrate content in soil decreased rapidly to very low levels (May, June).

In contrast to the first year the winter in both the following years (1995/96 and 1996/97) were cold with frozen soils and low precipitation. In autumn, nitrate development was similar to the first year but did not reach quite the same high level.

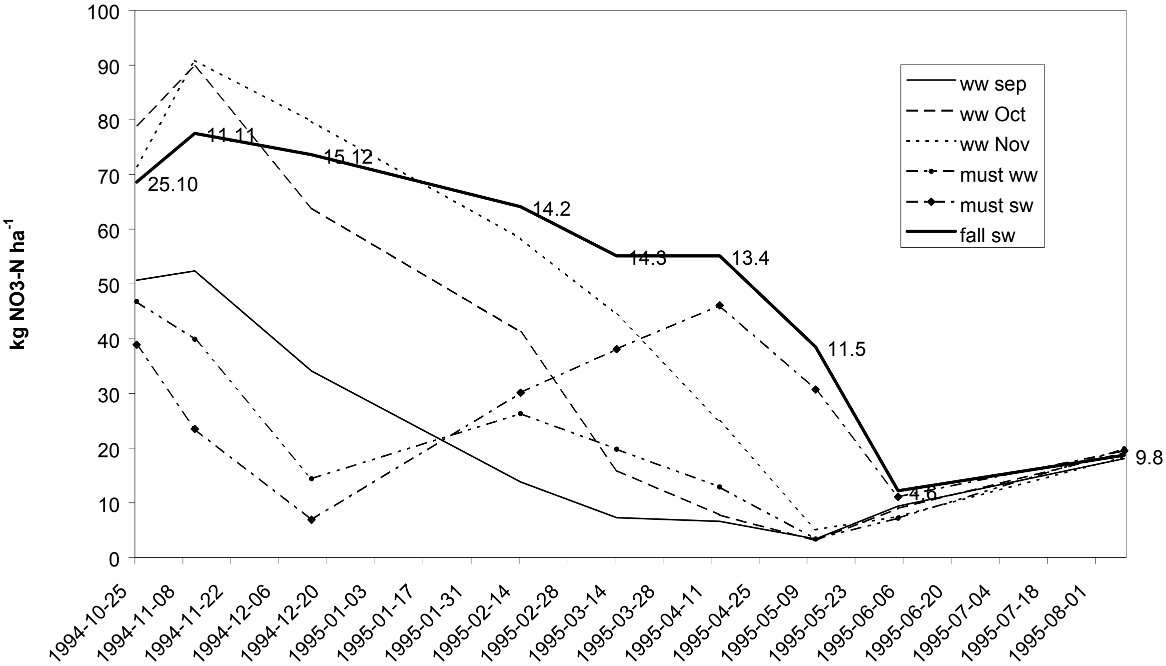

Figure 1 Nitrate dynamics in the soil layer 0-90 cm under winter wheat grown with different cultivation methods during 1994/95.

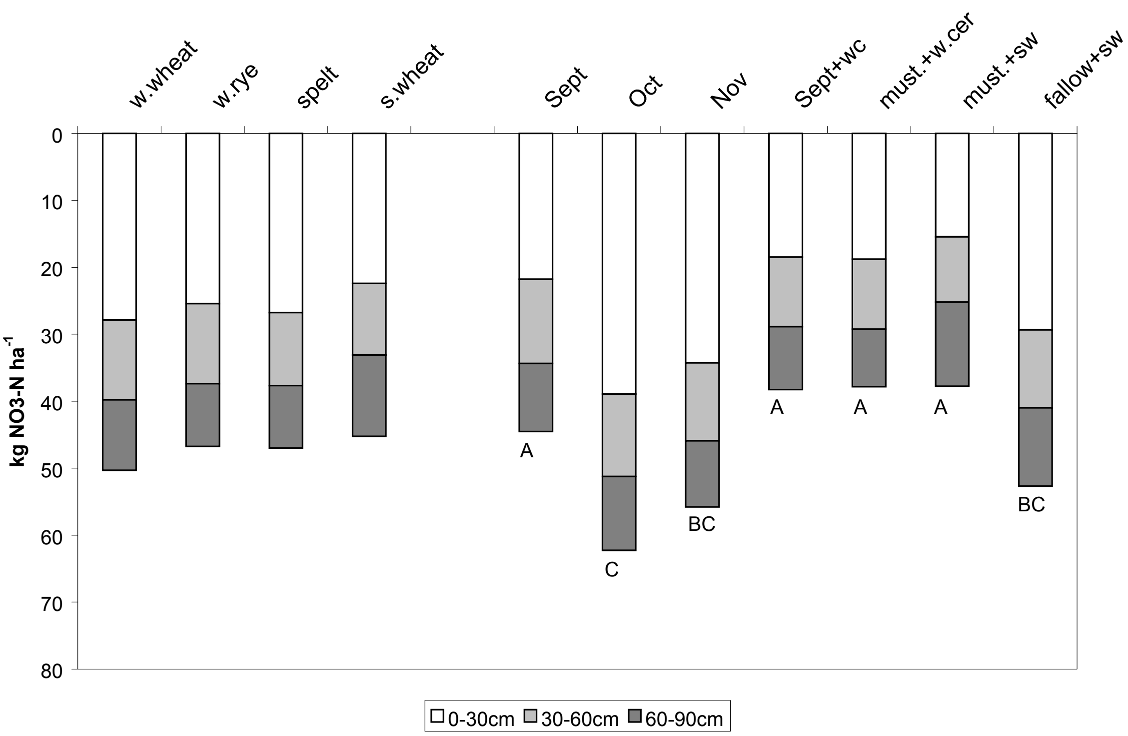

Figure 2 Nitrate in soil (0-90 cm) at the end of October differentiated by cereals and cultivation methods.

The statistical tests of both years together showed that there was no difference in soil nitrate content in winter and early spring among winter wheat, winter rye and spelt. The main differences in soil nitrate content resulted from the different cultivation methods. In October the lowest content in 0-90 cm was found under the mustard catch crop but the early sowing (Sep) almost reached the same low level especially when intercropped with white clover (Figure 2). By December the differences between the treatments had increased. While the mustard catch crop and September sowing had a content of 20-28 kg N ha^{-1} in 0-90 cm, the level of October and November sowings were 100% higher (Figure 3).

In early spring under September sowing the level decreased to 10 kg NO_3-N ha^{-1} (Figure 4). For the October sowing, the nitrate content also decreased while November sowings stayed at December's level. Due to soil cultivation in spring and the decomposition of the mustard catch crop, there was an increase in nitrate in the spring wheat treatments.

The extent of nitrate leaching during winter was examined by measuring the nitrate content in the soil layer between 90-150 cm (Figure 6). The highest level was found under fallow but the content under October and November sowings was only slightly lower. Significantly lower leaching rates were detected under early sowings in combination with catch crops. Due to the cold and dry winter weather in the second and third year nitrate leaching down to the layer of 90-150 cm was low in comparison to the first year, where the treatments had caused greater differences (Figure 6). But the results of the August sampling showed that under these soil conditions the roots of the cereals had been able to take up nitrate from the soil layers 90-150 cm and prevented further leaching (Figure 5).

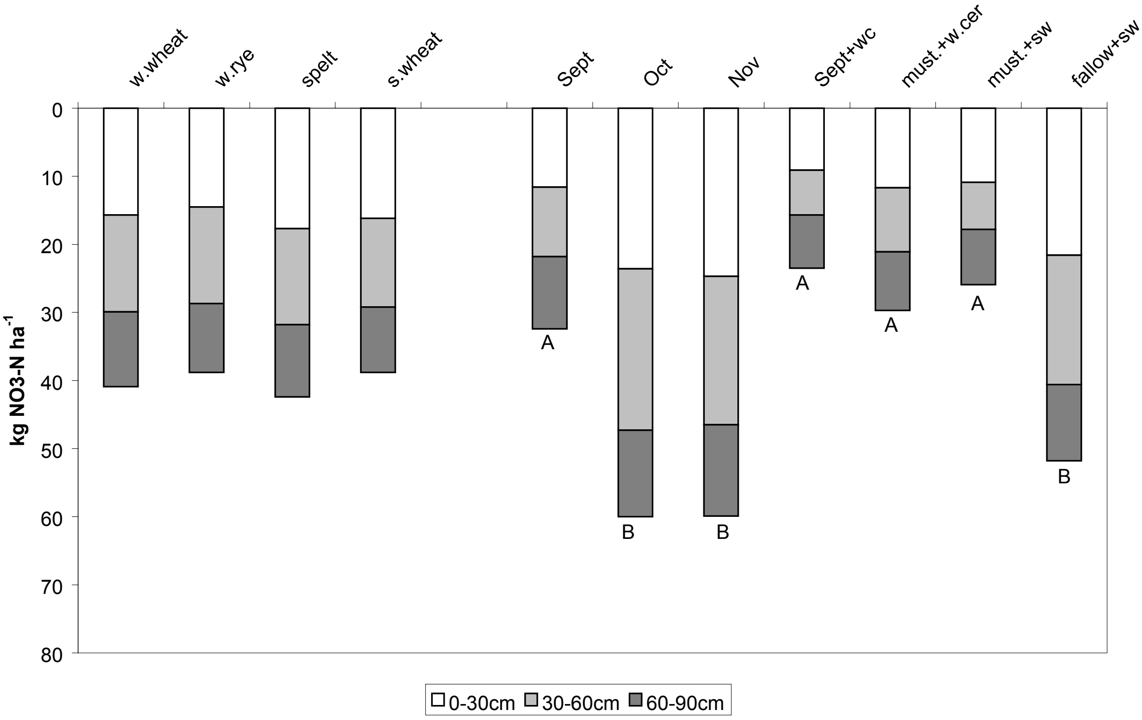

Figure 3 Nitrate in soil after mid December differentiated by cereals and cultivation methods.

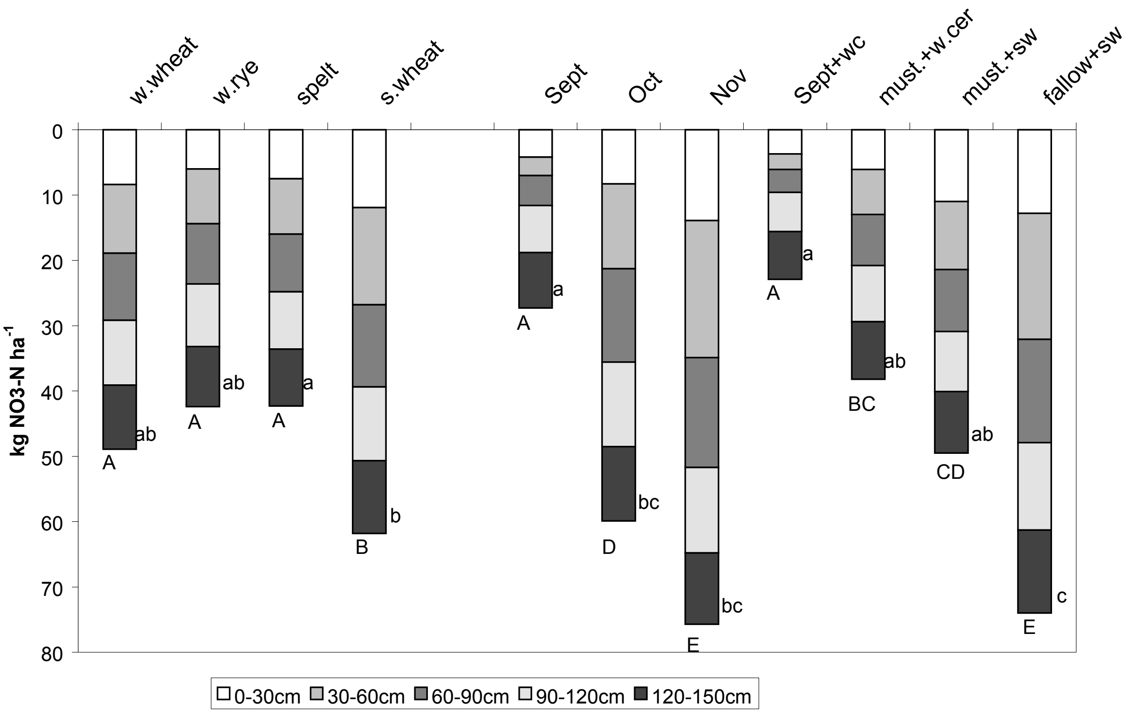

Figure 4 Nitrate in soil in the begin of April differentiated by cereals and cultivation methods; AB...: different characters = L.S.D. $p<0.05$ for sum 0-150 cm , ab...: L.S.D. $p<0.05$ for sum 90-150 cm.

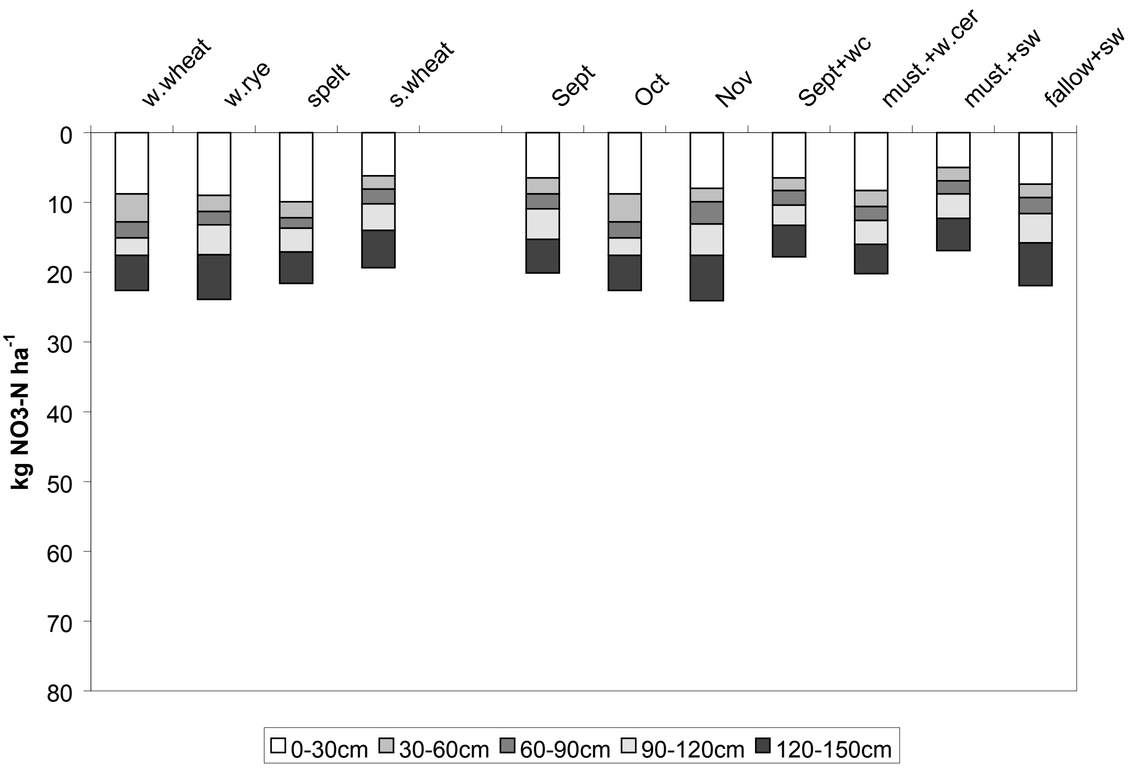

Figure 5 Nitrate in the soil 0-150 cm in August differentiated by cereals and cultivation methods.

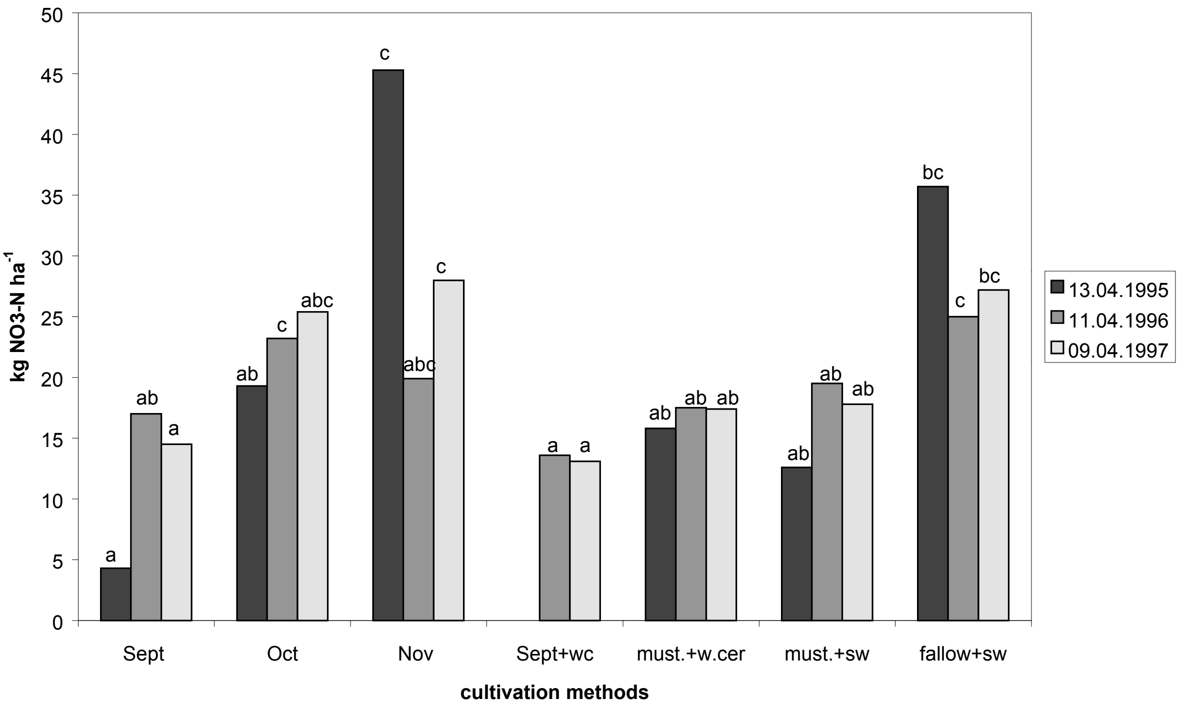

Figure 6 Nitrate in the soil layer 90-150 cm in the begin of April differentiated by cultivation methods and the weather conditions of the three experimental years; different characters: LSD. $p<0.05$.

Plant growth, yields and quality

In addition to nitrate dynamics in the soils, plant growth and nitrogen uptake was also measured. At the end of autumn the early cereal sowing had grown to 5-6.8 dt biomass ha^{-1} and accumulated 25-30 kg N ha^{-1} (Table 2). Nitrogen uptake of the mustard catch crop reached the same level under cold weather conditions but in the first year the N-uptake was significantly higher (Table 3).

At the beginning of the growing period in April, the September sowings had grown the highest biomass with more than 11 dt ha^{-1} combined with a N-uptake of 31 kg N ha^{-1} (winter wheat) to 39 kg N ha^{-1} (winter rye) (Tables 2 and 3).

In May the differences in plant growth increased between the different cereals but decreased according to the cultivation methods. Thus rye grew to have the highest biomass but had the lowest N-content followed by spelt and winter wheat. October and November sowings had a significantly higher growth rate than the September sowing. In June 66-75% of the biomass yield had been achieved with a N-uptake of 70-80 kg N ha^{-1} while the ranking of cereals and cultivation methods with regard to plant biomass did not change in comparison to May (Table 2).

Table 2 Biomass and yield in different cereals and different cultivation methods (1996-1997). Numbers within a column with different letters are significantly different at the 5 % level.

	Biomass (hkg ha^{-1})				Grain yield hkg ha^{-1}	Straw DM yield hkg ha^{-1}
	Dec	Apr	May	Jun		
winter wheat	5.8	6.7^{a}	14.2^{b}	55.4^{b}	40.2^{b}	45.9^{b}
winter rye	6.5	8.4^{b}	23.3^{c}	62.8^{b}	43.9^{b}	52.8^{c}
spelt	6.7	8.8^{b}	17.1^{b}	61.3^{b}	30.3^{a}	50.6^{c}
spring wheat			3.8^{a}	26.5^{a}	26.0^{a}	35.7^{a}
September sowing		11.7^{c}	23.3^{c}	72.7^{c}	42.9^{d}	57.0^{b}
October sowing		6.6^{b}	20.5^{c}	65.0^{c}	45.5^{d}	58.0^{b}
November sowing		1.8^{a}	10.7^{b}	47.5^{b}	35.1^{bc}	48.6^{b}
September+wc		12.6^{c}	23.0^{c}	71.3^{c}	39.9^{cd}	50.4^{b}
must.+w.cereals		5.2^{b}	13.5^{b}	42.8^{b}	27.3^{a}	34.8^{a}
must.+sw	6.8		3.1^{a}	23.8^{a}	23.4^{a}	33.9^{a}
fallow+sw			4.5^{a}	29.1^{a}	28.5^{ab}	37.6^{a}

Table 3 Nitrogen uptake and nitrogen content in different cereals and different cultivation methods (1996 -1997). Numbers within a column with different letters are significantly different at the 5 % level.

	N uptake (kg N ha^{-1})	Nitrogen content in DM (%)				
	Dec	Apr	May	Jun	Grain	Straw
winter wheat	25.0	3.27^{b}	2.48^{b}	1.29^{b}	1.62^{b}	0.49^{d}
winter rye	28.5	3.02^{a}	2.10^{a}	1.05^{a}	1.36^{a}	0.47^{b}
spelt	27.0	3.20^{ab}	2.17^{a}	1.22^{b}	1.93^{d}	0.38^{a}
spring wheat			2.81^{c}	1.76^{c}	1.83^{c}	0.51^{d}
September sowing		3.04^{a}	2.04^{a}	1.07^{ab}	1.59^{ab}	0.42^{ab}
October sowing		3.43^{b}	2.26^{a}	1.23^{b}	1.63^{ab}	0.46^{abc}
November sowing		3.60^{b}	2.95^{b}	1.59^{c}	1.76^{cd}	0.50^{bc}
Sept+wc		2.84^{a}	1.99^{a}	0.96^{a}	1.54^{a}	0.41^{a}
must.+w.cereals		3.06^{a}	2.01^{a}	1.09^{ab}	1.67^{bc}	0.46^{abc}
must.+sw	27.8		2.68^{b}	1.69^{cd}	1.79^{de}	0.47^{abc}
fall.+sw			2.93^{b}	1.83^{d}	1.88^{e}	0.54^{c}

The grain yields of the different cereals responded in the following order: winter rye ≥ winter wheat > spelt > spring wheat. The effects of the different cultivation methods were, however, higher. October and September sowings (without white clover) provided highest yields while those of November sowings were significantly lower (Table 2). Intercropping with white clover decreased yields of winter rye and winter wheat, whereas spelt was not influenced. Winter cereals in combination with mustard catch crop had the lowest yields compared with spring wheat after fallow. But not only winter cereals were affected by mustard, the yields of spring wheat also decreased.

The N-content content of the kernels was highest in spelt, followed by spring wheat, winter wheat and winter rye (Table 3). The differences between the cultivation methods were the same for all cereals. November sowing led to the highest N-content followed by the combination with mustard. October and September sowings had a significantly lower N-content in comparison with November sowing. Intercropping with white clover resulted in low grain quality especially in winter wheat (not shown). The N content also decreased in spring wheat when grown in combination with a catch crop.

Discussion

Root crops are frequently used as an important part of crop rotations in organic farming. During the change from one crop to the next, intensive tillage stimulates turn-over of soil organic matter and consequently the nitrate content in the soil increases. Nitrate accumulation in autumn may pose a risk because of the leaching processes during winter time. Experimental results have shown that nitrate contents increased up to a maximum of 80 kg NO_3-N ha^{-1} in a soil layer of 0-90 cm after the harvesting of potatoes. This level is lower than several results already published (Alföldi *et al.*, 1992; Paffrath, 1993; Wistinghausen, 1984) and values detected on some farmer's fields, but it exceeds the limit of 45 kg NO_3-N ha^{-1} which has been stipulated for water protection areas.

A critical examination of different cultivation methods does not reveal differences between cereals with regard to their efficiency in nitrogen uptake. The nitrate level in the soil increases with the duration between potato harvest and the sowing date of cereals especially under humid and mild weather conditions in autumn and the winter. Differences are reduced by cold and dry weather. Under such conditions September sowings can compete with catch crops. Only under better weather conditions mustard catch crop absorbs a greater amount of N. Measurements in early spring show that early sowing prevents nitrate leaching by having the lowest nitrate content in the 90-150 cm layer.

Plant growth rate in springtime is reduced in comparison to October and November sowings since the N-uptake from upper layers is also high. That is the reason why yields and the yield quality of September and October sowings are almost the same with slight advantages for October sowing. The favourable effect of a mustard catch crop for the prevention of nitrate leaching is combined with a significant decrease of plant growth, yield and yield quality in winter wheat as well as in spring wheat. The attempt to promote the N-uptake of cereals by intercropping with white clover, the N_2-fixing legume, was not successful. However it is the best method to prevent nitrate leaching, but it is unfortunately combined with lower yields.

The results show that changes in management (sowing time or catch crops) are able to reduce the nitrate content in upper soil layers and to reduce leaching into the ground water without requiring a change in the crop rotation. However successful nitrate uptake reduces nitrogen availability in springtime, which means that fertiliser such as urine or slurry should be added. Problems with the early sowning of cereals include higher coverage of weeds and risk of disease infestation e.g. with Septoria tritici.

Acknowledgements

The work was carried out under a grant from the Bavarien Ministry of Food, Agriculture and Forestry.

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The proportion of green fallow in stockless farming systems: grain N yield, N leaching, and soil organic N

H. Høgh-Jensen
Plant Nutrition Laboratory, Royal Veterinary and Agricultural University, Thorvaldsensvej 40, DK-1871 Copenhagen, Denmark

Summary

There is a need for increasing organic grain production. Here I have investigated the question of choosing the optimal proportion of ley in the crop rotation for stockless farming systems using a modified single-crop ley module to the mechanistic-based plant-soil-atmosphere simulation model DAISY. Two extremes were investigated; a nitrogen-conserving contra a nitrogen-leaky system. A clay-loam soil with a moderate water percolation were chosen as the conserving system and a sandy soil with a high water percolation were chosen as the leaky system. In all cases cereal straw was kept in the system, a grain legume was included in the rotation when possible, and the grass-clover herbage was exported. In addition, undersown catch crops and green manures (undersown in the cereals) were established under most cereals.

In the nitrogen conserving system, the ley proportion should not exceed 11% of the whole rotation as this gave a high yield potential, a low nitrogen leaching and a moderate increase in soil organic nitrogen.

In the nitrogen-leaky system, the ley proportion seem optimal around 11% of the whole rotation as this gave the highest yield potential, a moderate nitrogen leaching and only a small decrease in soil organic nitrogen.

Access to animal manure or other nitrogen containing residues may be a prerequisite to obtain an economically viable outcome in a leaky system whereas this is less important in a nitrogen conserving system. In all cases, the access to even small amounts of residues may significantly alleviate the decrease in soil organic matter that otherwise is encountered by many management practices.

A rhizodeposition of 120 kg N ha^{-1} yr^{-1} was used in the simulations. This amount of rhizodeposition is an approximation and investigations are needed on this aspect because complete cropping systems including semi-perennial crops like grass-clover can only be simulated by the inclusion of rhizodeposition. The present results indicate that 120 kg N ha^{-1} yr^{-1} is a conservative estimate.

Introduction

There is a strong need to increase the production of organic grain for human and livestock consumption (Anonymous, 1999). Grass-clover leys are popular elements in organic cropping systems because they supply a good quality fodder, as well as accumulating organic nitrogen (N) that the subsequent crops can benefit from (Johnston *et al.*, 1994). In many cases, however, the fodder produced in the ley phase do not have the same economic value as for example a cereal crop would have. Thus, farmers need to know the optimal proportion of ley in legume-based stockless cropping system.

However, to answer such a question the crop rotation or the farm unit must be viewed as a whole. In some regional areas, there is a sparse animal production and animal manure is thus only available in limited amounts. Large regional areas like for example Eastern and South-Eastern Denmark or Eastern Germany as well as Southern Europe has lacked behind in adapting the organic management techniques. This can to some extent be ascribed to the problem of obtaining a production level that is economic acceptable. In addition, smaller local areas (one or more farms) will also be without access to animal manure or other forms of organic manure because manure is a bulky product and animal production tends to become a large industrial enterprise. In other cases, the available residues may be of an unwanted quality, considering e.g. GMO and heavy metals.

Productivity, equity, sustainability and stability have been identified as key goals of agriculture (Conway, 1994) but they may not always be mutually consistent. In this contribution, I focus on estimating the optimal ley proportion in the rotation on stockless farms. The weight is towards the ecological imperatives, which after all is a precondition for a sustainable productive agriculture. The emphasis will be on grain production in relation to production output from the system (grain N yield), N leaching from the system, and the organic N content in the soil. These three parameters are considered for a sandy loam[1] under climatic conditions general for Western Denmark and a clayey loam[2] under climatic conditions general for Eastern Denmark with different proportions of green fallow. To consider the grain production and the N leaching it is necessary to understand the N dynamics in the whole cropping system, i.e. over several years. In organic farming systems, the N dynamics are dominated by the turnover of organic manure and crop residues and, in turn, this turnover is influenced by fluctuations in soil water content and soil temperature.

Materials and methods

In Denmark fertilisation with N is a regulated affair where the needs for each specific crop have been estimated under different climatic zones and on different soil types; selected examples are shown in Table 1. We will consider the two scenarios of (i) no import at all or (ii) import of manure (pig slurry) equivalent to 20% of cereal's N demand according to official norms for a clayey soil (Table 1) in total-N. This is equivalent to 14% of N demand of cereals based on the NH_4^+-N content. These scenarios will be simulated on soils with clay contents of 12% or 4% under climatic conditions as described below. In the calculation of N demands, the fertilisation norms of leys are set to zero.

[1] Such a soil is in Denmark classified as JB 1, which is comparable to St. Jyndevad Research Station or to the sandy parts of Askov Experimental Station.

[2] Such a soil is in Denmark classified as JB 6, which is comparable to Højbakkegård at KVL or to the clayey parts of Askov Experimental Station.

Table 1 Nitrogen norms for selected crops according to the Danish Ministry for Foods, Agriculture and Fisheries. The norms are for a sandy soil in Westernt Denmark and for a clayey soil in Eastern Denmark (Anonymous, 1998).

Crop	Sandy soil (kg N ha^{-1})	Clayey soil (kg N ha^{-1})
Spring barley after continuous cereals	134	117
Oats	103	87
Winter wheat after grass-clover	130	127
Winter wheat after continuous cereals	187	184
Winter barley after continuous cereals	150	142
Winter rye after continuous cereals	120	108
Pea	0	0

Table 2 Six simulated crop rotations where the first line is the first year, line two year two and so forth. The grass-clover ley (ley) is established by undersowing in a spring barley crop (S.Barley-u). In those cases where manure is applied the amount is shown also.

	Proportion of green fallow in the crop rotation					
	0%	11%	17%	20%	25%	40%
Element	S.Barley	S.Barley-u	S.Barley-u	S.Barley-u	S.Barley-u	S.Barley-u
in the rotation	S.Barley	Ley	Ley	Ley	Ley	Ley
	Pea	W.Wheat	W.Wheat	W.Wheat	W.Wheat	Ley
	W.Wheat	W.Barley	W.Barley	Pea	W.Barley	W.Wheat
	W.Barley	Pea	Pea	W.Barley		W.Barley
		W.Wheat	W.Wheat			
		W.Barley				
		Pea				
		W.Wheat				
Total-N application per rotation (kg N ha^{-1})	112	179	114	77	77	77
(kg N ha^{-1} yr^{-1})	22.4	19.9	19.0	12.9	19.3	15.4

Description of the farm management and simulations

Here I have proposed six possible crop rotations (Table 2) with a varying degree of green fallow. All cereals are grown with an undersown mixture of grass-clover serving both as a catch crop and as a green manure crop. For the sake of simplicity, they do not differ between the investigated scenarios.

It is realised that it is necessary to use different cereals to prevent diseases like e.g. nematodes. However, some crop modules are not developed for DAISY, e.g. for rye or oats. Thus, similar crops are used instead in the simulations (Table 2). The ley is mowed and the shoot material is taken away from the field. To enable mechanical weed control cereal straw is removed from the field for one course in each rotation and, likewise, the straw is removed when the ley phase is established but otherwise left on the stubble for subsequent incorporation.

The sandy soil was irrigated every time the soil water deficit reached 30 mm in order to eliminate significant effects of water deficiencies on plant growth.

Simulations

The simulations were conducted with a standard version of the mechanistic-based plant-soil-atmosphere DAISY model (Hansen *et al.*, 1993). This model is described thoroughly elsewhere (http://www.agsci.kvl.dk/planteer/daisy/daisy.htm) and interested are referred hereto (see also Jensen *et al.*, this volume). However, ley is a dominating crop and so far we have not operated with an official grass-clover module to DAISY. Høgh-Jensen (1996) and Høgh-Jensen & Schjoerring (1997) used a modified single species module to simulate grass-clover with some success.

Presently, DAISY is under re-coding to a version that will enable the simultaneous growth of multiple species and include root turnover among other improvements. However, in this study we will operate with a further modified version of the grass-clover module described by Høgh-Jensen (1996). This module was tested towards partly independent data of a crop rotation on Højbakkegård, 20-km vest of Copenhagen (55°40'N, 12°18'E, 28 m above MSL). The module gives a realistic picture of the production on field level under varying precipitation condition; starting with tree dry years, ending a with two years with abundant precipitation, and the years in between as intermediate (Figure 1). It is seen that the measured amount of nitrogen in the root system is not the same as the predicted. The simulated values are nevertheless considered realistic as the washing procedure of the soil cores leads to significant losses of root tissue and water-soluble N (e.g. McNeill *et al.*, 1997).

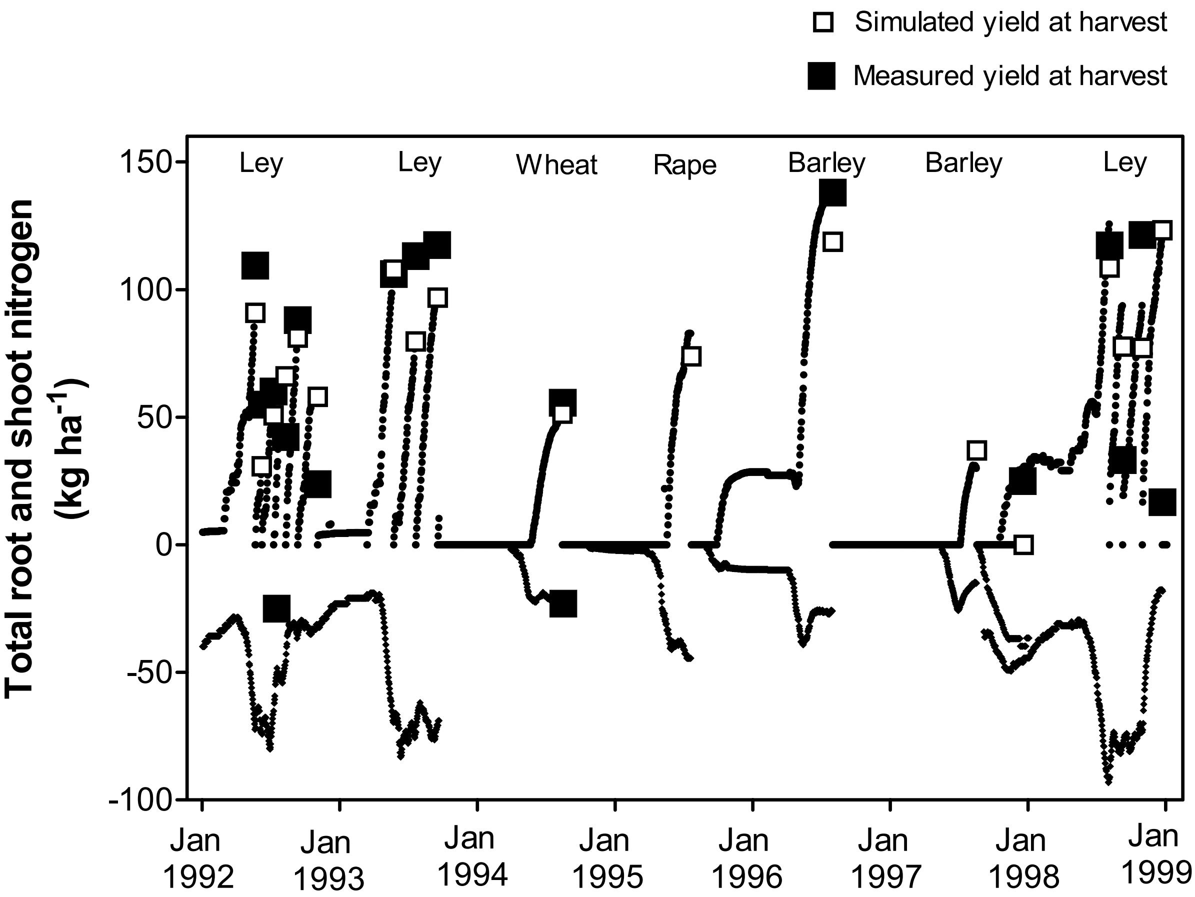

Figure 1 Nitrogen accumulation in above-ground (positive values) and below-ground (negative values) biomass from data obtained from farm data at Højbakkegård (squares) compared with simulated nitrogen accumulation (dots) using the grass-clover module in the period 1 January 1992 to 31 December 1998.

Each simulation was run for two full crop rotations (Table 2) but only data from the second cycle is used in the following. Furthermore, N balances were calculated on whole year basis with 1st April as the starting date. This procedure was chosen in order to eliminate influence of the initial settings of inorganic and organic N pools as well as soil water content.

In semi-perennial ley systems, rhizodeposition is a factor that must be included in the N dynamics. The root system of ryegrass has been found to turnover twice during a growing season (Sauerbeck *et al.*, 1981; Thoughton, 1981). Assuming turnover rates for white clover of four and a total root size equivalent to 80 kg N ha^{-1} (Figure 1) and a immobilisation rate of 50% would lead to a deposition of approx. 120 kg N ha^{-1} yr^{-1}. Such a rhizodeposition agrees to some extent with the response curve determined by Johnston *et al.* (1994) and the rhizodeposition found by McNeill *et al.* (1997; 1998). Assuming a C:N ration of 16, this amount of organic material is thus added each year by the end of the growing season when a grass-clover ley is included.

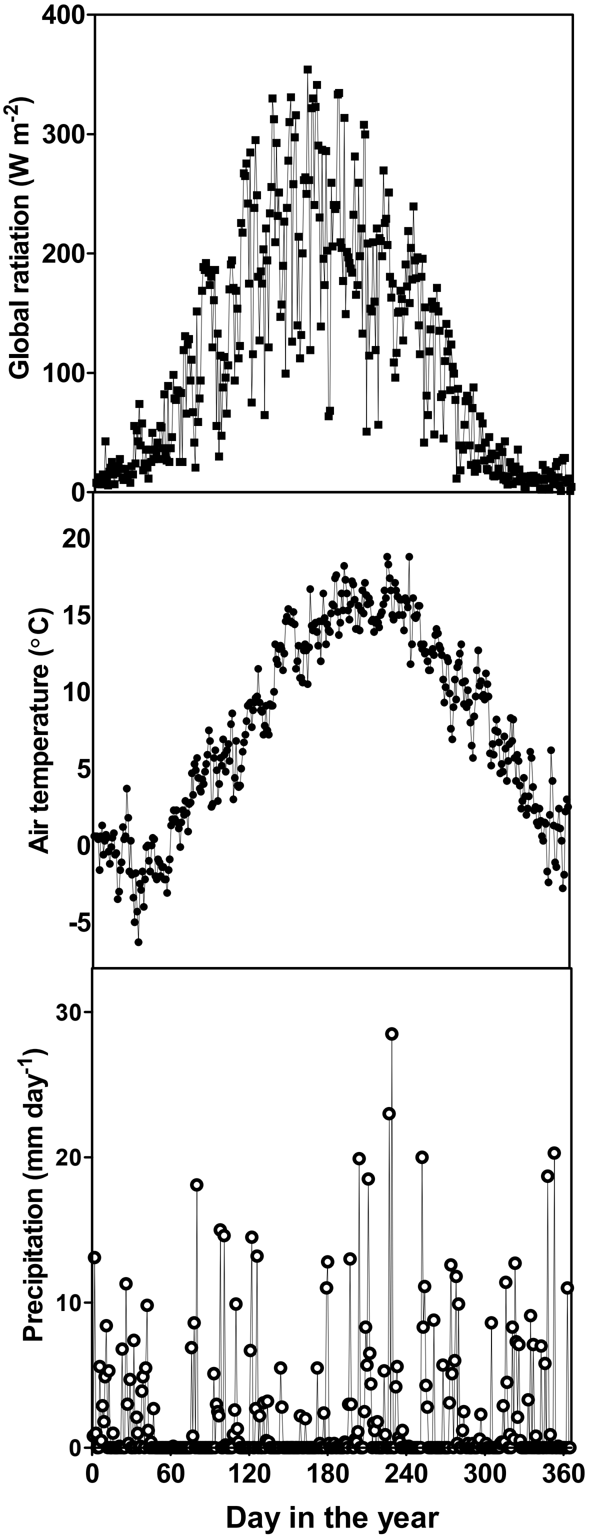

Figure 2 The constructed normalised climate used for simulations reflecting Eastern Denmark.

Climate

The driving variables in DAISY are global radiation, air temperature, and precipitation. The two climates used in the simulations are normalised climates. Hansen & Svendsen (1994) and Børgesen *et al.* (1997) described the methodology used in constructing the climates. In brief, the measured climate on Højbakkegård from 1955-1979 was analysed on a monthly basis for precipitation and temperature. Subsequently, the month closest to the true average was selected, which ensures a realistic description of both leaching and mineralisation. The constructed normal-climate for Eastern Denmark is shown in Figure 2. The climate used for Western Denmark is similar in terms of radiation and air temperature but precipitation is approximately 20% higher (780 mm yr^{-1} versus 990 mm yr^{-1}).

Results and discussion

A crop rotation is not static in it self. It will constantly be modified by the farmer according to market movements, changes in stock needs for fodder, new crops species available, new technology, performance by preceding crops, as well as problems with weeds, pests and diseases. Also, over time the specific crop rotation will seek towards a new homeostasis in soil fertility.

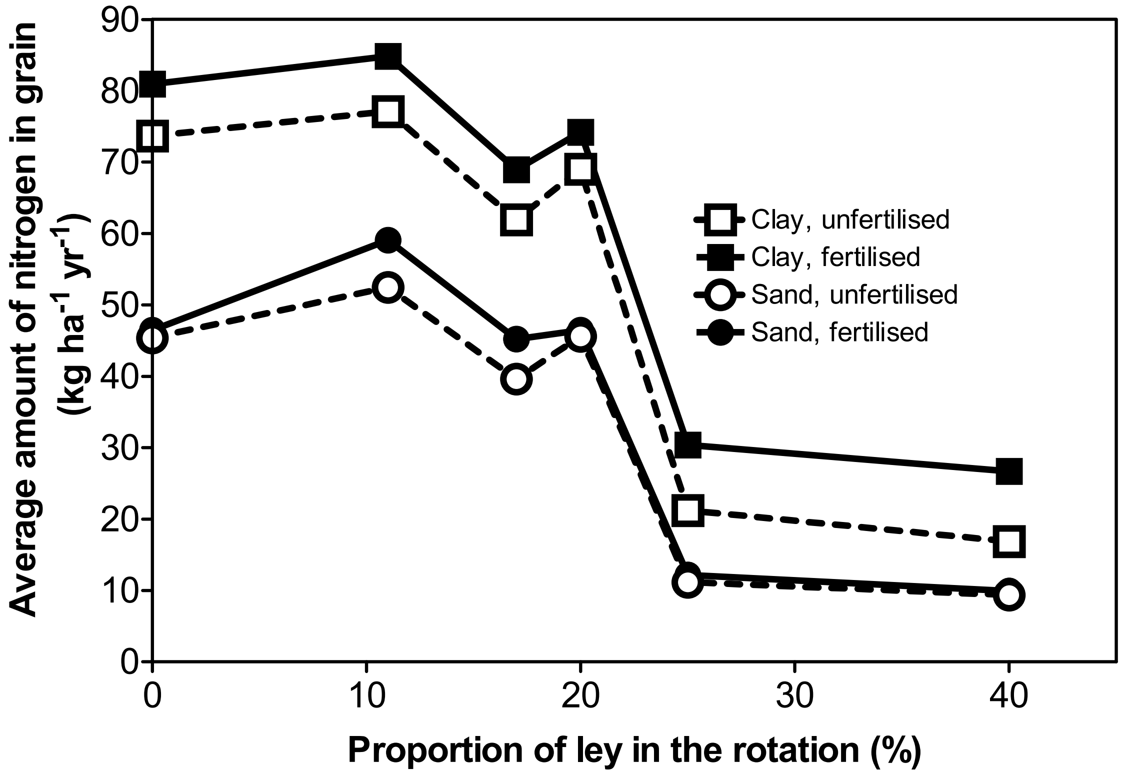

Figure 3 Simulated nitrogen accumulation in grain as a function of proportion of ley in the crop rotation as average per hectare per year for the whole crop rotation for a sandy soil in Western Denmark and a clayey soil in Eastern Denmark that received either no fertiliser or pig slurry equivalent to 20 % of the cereals N need according to norms.

Yield potential of the system as reflected in the harvested grain nitrogen

Grain is the cash crop in this farming system. Thus, the total output of grain from the farm is important for the economic sustainability. Measured in produced grain-N as an average of the total crop rotation it is very distinct that the output drops above 20 % of ley in the crop rotation (Figure 3). It must be realised that a grain legume (pea) is included in the crop rotations when ever possible.

It is noteworthy that application of a moderate amount of manure indeed stimulates the production on both soil types. However, on a sandy soil with a low ley content hardly any stimulation is noticed. The simulations indicate that undersowing of catch crops and green manures as well as inclusion of a ley component in the cropping system is not enough to ensure a high production level of grain under N-leaky conditions, i.e. a sandy soil with a high rate of percolation.

On a clayey soil, it is concluded that the proportion of ley in an otherwise agronomically sound crop rotation does not need to exceed 11% of the total area. This contrast with Bulson *et al.* (1996) who under comparable condition - a similar precipitation, on a similar soil type, with 20% of the area allocated to a green manure crop (red clover) - concluded that those crops placed most unfavourable in the rotation showed decreasing yields. Their crop rotation, however, did not include a grain legume and did not utilise undersown catch and green manure crops.

On a sandy soil, the optimal ley proportion is around 11% of the cropping system. However, these systems are clearly nitrogen limited and such systems may only be economically viable when nutrients can be imported because the simulated grain yields would not be acceptable from the farmer's point of view as for example the crops competitiveness against weeds would be very small.

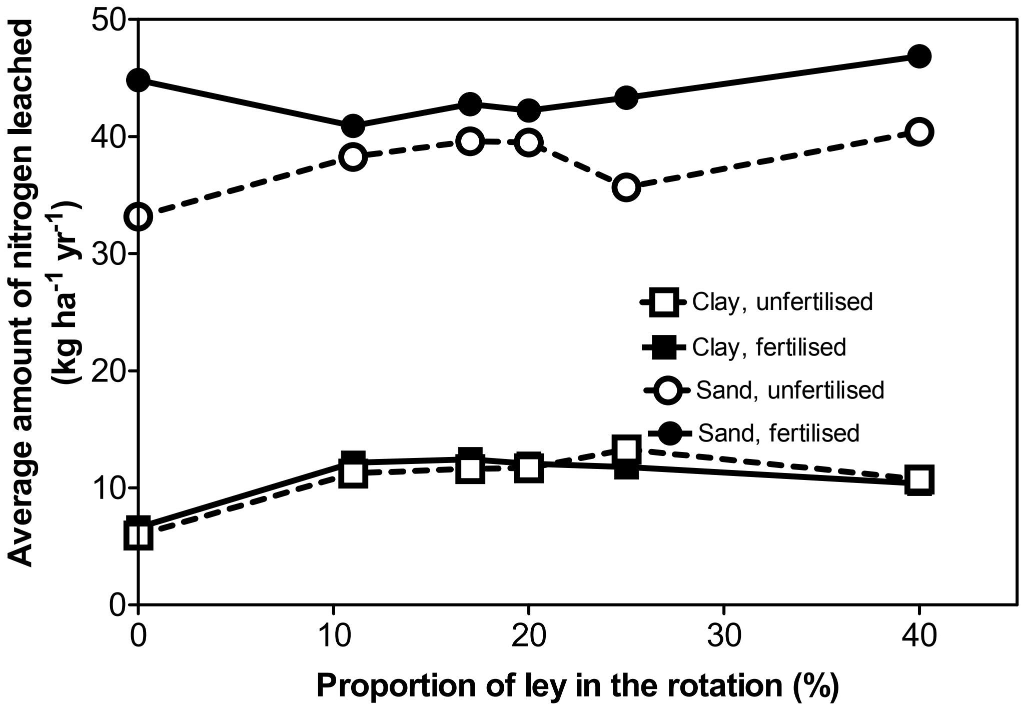

Figure 4 Simulated nitrogen leaching as a function of proportion of ley in the crop rotation as average per hectare per year for the whole crop rotation for a sandy soil in Western Denmark and a clayey soil in Eastern Denmark that received either no fertiliser or pig slurry equivalent to 20 % of the cereals N need according to norms.

Nitrogen leaching

Very little information is available regarding nitrate leaching from organic stockless farming systems as reviewed by Hansen (1998). The present study indicates that the leaching is very moderate on a clayey soil (6-13 kg N ha^{-1} yr^{-1}) where none or only limited amounts of manure are available (Figure 4). These values agree with Schmidt *et al.* (1996) who worked under a similar precipitation but without given any description of the soil mineralogy.

On the contrary, on a sandy soil with a high percolation rate such systems may leach significant amounts (33-56 kg N ha^{-1} yr^{-1}) although crops as much as possible cover the soil. With the present percolation, these amounts will result in nitrate concentrations in the ground water around 25 mg L^{-1}.

Using an empirical relation (see Simmelsgaard, 1997), Hansen & Kristensen (1998) estimated a leaching for stockless farming systems of 19 and 36 kg N ha^{-1} yr^{-1} on soils with clay contents of 14.2% and 5.1%, respectively. Despite the very different methodology, the amounts are in agreement with this study.

The present mechanistic-based simulations indicate that the proportion of ley in the cropping systems do not influence the N leaching to any significant extent. It is the hydraulic conductivity and the winter precipitation that clearly determines the leaching rate. This is seen from the ratio of N release:N losses (mineralisation:leaching), which on average is 0.62 for the leaky system and 0.17 for the conserving system.

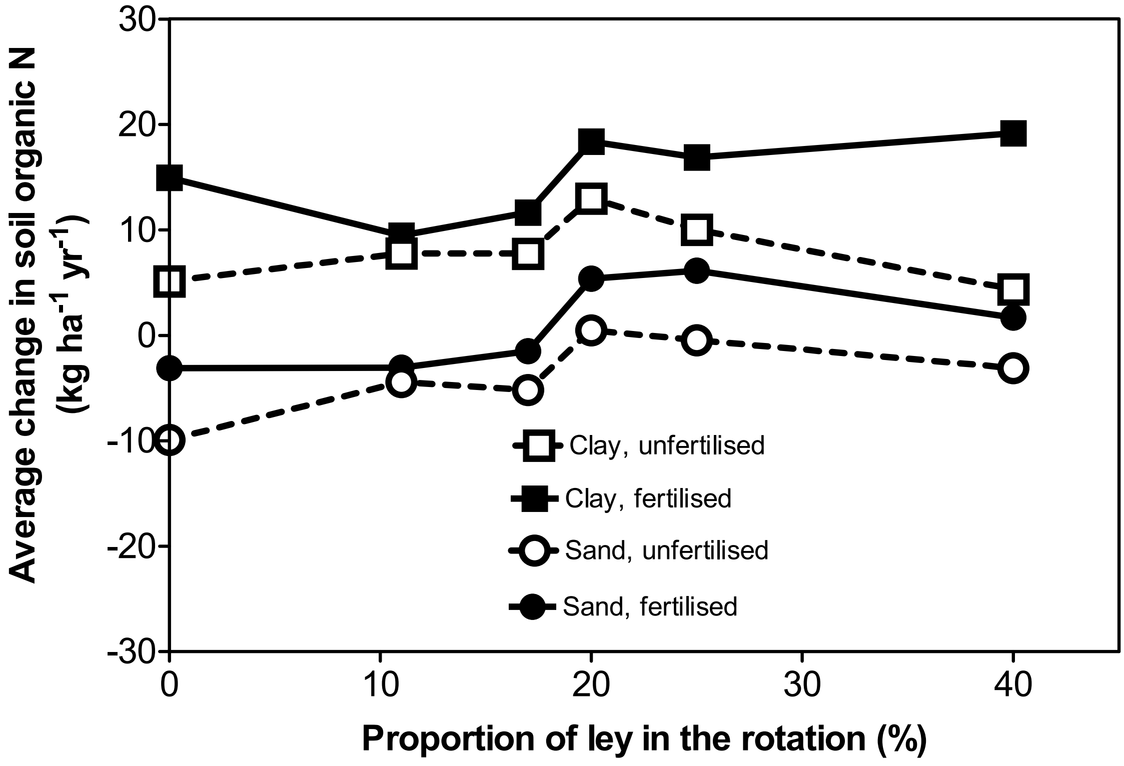

Figure 5 Simulated change in soil organic nitrogen as a function of proportion of ley in the crop rotation as average per hectare per year for the whole crop rotation for a sandy soil in Western Denmark and a clayey soil in Eastern Denmark that received either no fertiliser or pig slurry equivalent to 20 % of the cereals N need according to norms.

Soil organic nitrogen

On soils with similar clay content as used in these simulations (approx. 12%) it has been found almost impossible to maintain the carbon content in the soil under normal management practices (Christensen *et al.*, 1994). On more sandy soils it seems only possible to maintain soil content of organic matter by applying very large amounts of animal manure (Christensen & Johnston, 1997). The present simulations do not fully agree with these observations. This can be explained by the fact that in the rotational trials at Askov and Rothamsted (Christensen *et al.*, 1994; Christensen & Johnston, 1997) plant residues were routinely removed from the system. On the contrary, in the present simulations straw were to the highest possibly extent maintained within the system and it is indicated that this practice would lead to an improvement of soil organic matter.

In agreement with common knowledge, the simulations showed an improvement in the organic matter in the soil by increasing the proportion of ley (Figure 5). Although the simulations operated with a rhizodeposition, increasing the ley phase from 20 to 40% of the rotation did not show the expected increase in soil organic matter. This indicates that the rhizodeposition may be conservatively estimated.

As the soil initially was determined to have approximately 8000 kg organic N ha^{-1} to a 1-m depth, the estimated changes in soil organic nitrogen is not considered as significant changes in soil fertility. However, application of small – as in this case – amounts of residues may significantly alleviate the otherwise constant decrease in soil organic matter.

Future challenges

The model used in these simulations is only partly able to include the mechanisms of rhizodeposition, the turnover of such deposition, and the competitive outcome following mineralisation. This will soon be alleviated by a versatile version of DAISY that can simulate the growth of several species, including root turnover. Note that these species must be characterised in their below-ground characteristics (rooting architecture, root turnover, rhizodeposition) as well as in their uptake capacities to get precise simulations of intercropped systems.

In the present study, 1600 kg C ha^{-1} (≈120 kg total-N) were added to the soil every time the ley had finished a full growth season. This approximation seems to give realistic estimates of the nitrogen dynamics in the cropping system. However, a lot of work awaits us ahead before we accurately will be able to predict the nitrogen dynamics in multi-species, legume-based, stockless cropping systems. It is thus important to remind us self about the importance of the cycling processes on the root surface for understanding nutrient management in systems that may be low-external-input systems but high-internal-input systems.

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Simulation of plant production and N fluxes in organic farming systems with the soil-plant-atmosphere model DAISY

L.S. Jensen[1], T. Mueller[1], J. Eriksen[2], K. Thorup-Kristensen[3] and J. Magid[1]
[1] The Royal Vet. and Agricultural University, Plant Nutrition and Soil Fertility Laboratory; Thorvaldsensvej 40, 1871 Frederiksberg C, Denmark
[2] Danish Institute of Agricultural Sciences, Research Centre Foulum, Denmark
[3] Danish Institute of Agricultural Sciences, Dept. of Fruit, Vegetable and Food Science, Research Centre Aarslev, Denmark

Summary

In organic farming systems nitrogen originates predominantly from nitrogen fixing crops, such as grass-clover leys or leguminous green manures. At times when nitrogen leaching would occur, catch crops may play a significant role in retaining excess labile N within the soil-plant system. Modelling crop production and N cycling in such cropping systems, presents a very different challenge compared to conventional, high input systems.

The deterministic soil-plant-atmosphere model DAISY was applied to two different systems: i) a stockless crop rotation where green manures and catch crops are used as the exclusive nutrient source, and ii) a perennial grass-clover ley (cut or grazed by dairy cattle) preceding a barley crop.

In this paper we present preliminary results from the on-going simulation work and special focus has been on i) the simulation of plant growth under such low input conditions, ii) the turnover of the incorporated plant residues in the soil, incl. N mineralisation and leaching, and iii) possible reasons for deviations between simulations and experimental results.

Introduction

One of the major challenges in sustaining agricultural plant production is to increase the nutrient cycling of the agro-ecosystem. Organic or ecological farming systems aim at increasing nutrient recycling and utilisation of natural nitrogen (N) sources, such as N in crop residues of N-fixing crops, green manures or catch crops. Appropriate crop rotation design is essential if this goal is to be pursued with any degree of success.

On organic dairy farms grass-clover pastures form a major constituent of most crop rotations, and the N input comprises both N fixed by the clover component and the variable amount of faeces and urine excreted in the pasture by the grazing cattle. Knowledge on how to increase transfer of residual N from these grass-clover pastures to other crops in the rotation is urgently needed (Høgh-Jensen & Schjoerring, 1997). Especially pertinent is the effect of sward composition, quality and history of use for the subsequent mineralisation of C and N and the risk of N losses by leaching (Hauggaard-Nielsen *et al.*, 1998).

On stockless organic farms on the other hand, full year green fallow, i.e. legume-grass mixtures, is commonly used at least once in every rotation, preceding the most N demanding crops. In addition, annual green manures and catch crops are used more and more intensively, to increase N recycling by reducing leaching, and supply more N through fixation, thus reducing the requirement for green fallow, which is an economically unfavourable component of the crop rotation. Furthermore stockless organic farms often grow vegetable crops, with short growing period, shallow root development and a temporal pattern of N demand radically different from most traditional arable crops. Thus, prediction of N supply and recycling in such cropping systems is essential in order to design appropriate crop rotations for stockless organic farms (Thorup-Kristensen & Nielsen, 1998).

Existing knowledge of N processes in the soil and N utilisation by crops has been used to formulate mechanistic models with increasing level of complexity and detail of both pools and processes (de Willigen, 1991). Many of these models have been developed and calibrated with data from conventional, high N input farming systems, and were furthermore developed with the aim of simulating N losses during the 1980ies, when environmental problems with N leaching became an issue of public concern.

Now, a fundamental question is of course: Do these models have the ability to simulate crop growth and N cycling in organic farming systems appropriately? One evident problem is the fact that the N inputs are lower and in organic form compared to the mineral fertiliser N inputs in conventional systems, and some modifications or re-calibration may have to be carried out. However, if existing, valid models can be applied, their use holds great prospects, because they can be a very powerful tool for evaluating the productivity, sustainability and environmental impact of different organic crop rotation strategies.

An early approach to this question was made by Magid & Kølster (1995), who applied a deterministic model to an organic dairy crop rotation, simulating crop production, N uptake and N losses over the 5 course rotation (barley-ley-ley-w.wheat-fodderbeet). They concluded that although the input of N in manure and N fixation more or less balanced with the harvested N output, some significant N losses must have occurred, as the application of manure for e.g. fodder beet was done in the autumn where the simulations indicated a large leaching loss. This would mean that there was a concurrent, albeit slow, depletion of soil organic N, and this was confirmed by the simulations. However, the only measured data available for the rotation were harvest yields and plant N content, and thus the conclusion could not be verified.

It may be concluded from the previous sections, that work on testing and validating deterministic models on more extensive data-sets from organic crop rotations has been urgently needed. Therefore, a project within the *Danish Research Centre for Organic Farming* (*DARCOF*) was initiated with the objectives of validating the deterministic soil-plant-atmosphere model DAISY (Hansen *et al.*, 1991b) for use on i) a stockless organic crop rotation, including vegetable main crops, at Aarslev, Denmark, with particular emphasis on the ability of the model to simulate the influence of catch crops and green manures on the subsequent plant growth and soil N turnover and ii) an organic dairy crop rotation at Foulum, Denmark, with particular emphasis on the residual N effect of incorporated grass-clover pastures on the soil C and N turnover, crop N uptake and subsequent N leaching, depending on pasture management. At both experimental sites, relatively extensive and detailed data-sets have been produced by other projects within *DARCOF*. This modelling work is currently on-going and some preliminary results and illustrations of current abilities and disabilities of the model will be presented.

Materials and methods

The data-sets and measured variables

The Aarslev data were from two of the fields in the stockless organic crop rotation, see Thorup-Kristensen (1999, this issue) for more details. The period simulated is from autumn 1995 (establishment of the organic crop rotation at Aarslev) until winter 1998/1999. The main focus in these two fields during that period was the crop sequence: green peas – *catch crop* – spring barley (*undersown legume grass*) – legume grass mixture as green fallow (whole year, one cut). Oil radish is used as the standard catch crop in the organic crop rotation, but other catch crops, e.g. ryegrass, winter rye, oats, winter oilseed rape and vetch, as well as no catch crop was studied in smaller plots. Measured variables included root growth of both main crops and catch crops, growth (yield and total DM production) and N uptake by both main and catch crops, as well as soil mineral N in 25 cm increments to 100 cm and in some cases as far as 150 cm depth.

The Foulum data were from an experimental site where the residual N effect of grass-clover pastures in organic farming systems has been studied. The experimental factors included sward type (grass-clover mixture or pure ryegrass, the latter fertilised with 300 kg fertiliser N ha^{-1} yr^{-1}) and sward use (cut or grazed, with an annual N excretion by grazing cattle of ca. 300 kg total N ha^{-1} yr^{-1}). The sward was three years old when it was ploughed under in the spring of 1997 and a crop sequence of spring barley - *ryegrass catch crop* - spring wheat - *ryegrass catch crop* - fodder beets introduced. Before sowing of barley and wheat, cattle slurry was applied at three different levels, corresponding to 0, 115 and 230 kg total N ha^{-1} (0, 62 and 124 kg NH_4-N ha^{-1}). A reference field without grass prehistory was also included, but with the same crops and with six increasing fertiliser N levels ranging from 0 to 150 kg N ha^{-1}. Measured variables included soil water content (continuous TDR in autumn 1997 and occasional gravimetric measurements throughout the period), soil surface CO_2 flux as an index of biological activity during the first 3 months after sward incorporation, growth (yield and total DM production) and N uptake by both main and catch crops, soil solution nitrate N content (sampled by ceramic suction cups installed at 100 cm depth in all fields with grass history) as well as soil mineral N in 25 cm increments to 100 cm depth.

The model

DAISY (Hansen *et al.*, 1991b) is a deterministic and mechanistic model that simulates the water and energy flows, the plant growth, and the C and N fluxes in the soil-plant-atmosphere system. It consists of sub-models for soil water (incl. solute movement), soil temperature, soil organic matter (incl. microbial biomass, SMB), soil mineral N, crop growth and system management. The original purpose of the model was to predict N-leaching and crop production in temperate, intensive cropping systems. Consequently, DAISY was originally calibrated on systems with high input of mineral fertiliser, liquid manure or farmyard manure. DAISY has been used as a management tool at field scale (Jensen *et al.*, 1994b), and in studies at catchment or regional scale (Styczen & Storm, 1993; Thirup, 1999). It has been extensively validated under various conditions (Hansen *et al.*, 1991b; Hansen *et al.*, 1991a; Jensen *et al.*, 1994a; Petersen *et al.*, 1995; Svendsen *et al.*, 1995). In addition, the performance of the DASIY model has several times been compared with other deterministic models, evaluating the models ability to predict N leaching and crop growth (de Willigen, 1991; Vereecken *et al.*, 1991; Diekkrüger *et al.*, 1995) or long-term changes in soil organic matter and soil fertility (Jensen *et al.*, 1997b; Smith *et al.*, 1997). In these comparisons, the model has always ranked among the best. Recently, the DAISY model has been tested and validated on detailed and comprehensive field data sets on soil C and N turnover (Jensen *et al.*, 1997a; Mueller *et al.*, 1997, 1998)

Parameterisation and general setup

In the current work, all model parameters were used as mentioned for the default setup of DAISY (Svendsen *et al.*, 1995), except for the soil organic matter module, where the recalibrated parameter set for turnover rates of SMB, added organic matter (AOM), incl. plant residues, and root organic matter (ROM), as well as substrate utilisation efficiencies have been used (Mueller *et al.*, 1998).

Driving variables for the simulation periods (global radiation, air temperature and precipitation) were derived from weather data collected at the Aarslev and Foulum weather stations, respectively. Precipitation data were corrected to surface level (Allerup & Madsen, 1980).

Table Fejl! Ukendt argument for parameter. Soil clay content, C_{org} content and C/N ratio of the Aarslev site.

		1996-97 exp.		1997-98 exp.	
Depth (cm)	**clay (%)**	**C_{org} (%)**	**C/N**	**C_{org} (%)**	**C/N**
0 – 25	14.6	1.9	11.6	1.4	10.2
25 – 50	18.7	0.7	10.6	0.5	8.2
50 – 75	21.3	0.3	9.0	0.2	6.2
75 – 100	20.2	0.2	5.3	0.2	4.5

*: Not determined, a C/N-ratio of 11 has been assumed in all the simulations.

Table 2 Soil clay content, Corg content and C/N ratio of the Foulum site.

	Reference			Grass pasture		
Depth (cm)	**Clay (%)**	**C_{org} (%)**	**C/N**	**Clay (%)**	**C_{org} (%)**	**C/N**
0 – 25	8.4	2.9	nd*	8.4	3.7	nd
25 – 50	7.9	1.4	nd	8.8	1.5	nd
50 – 75	7.3	0.6	nd	11.9	0.3	nd
75 – 100	7.7	0.1	nd	13.8	0.1	nd

*: Not determined, a C/N-ratio of 11 has been assumed in all the simulation.

Soil clay content, total C and total N were defined as measured in the fields before establishment of the experiments in Aarslev and Foulum (Tables 1 and 2). In order to define the soil physical properties, hydraulic and thermal conductivity and water retention curve data from adjacent, very thoroughly physically characterised fields in Aarslev and Foulum were used.

Measured data of SMB-N from some of the fields at both the Aarslev and the Foulum site (unpublished data) were used for the initiation of the SMB-pools, assuming an SMB-C/SMB-N-ratio of 7 (Jensen *et al.*, 1997a). Furthermore it was assumed, that the relative amount of total soil C present as SMB-C was the same in the other soils at the respective site in the beginning of the simulation period.

The initial mineral N contents were adjusted in order to fit the first measured values. In one of the two Aarslev fields, a slurry application at the initiation of the rotation was defined using measured data of NH_4-N and standard data for other parameters.

Table 3 Parameters of the root growth used in the crop modules for the Aarslev site, according to measured data (Thorup-Kristensen, 1997; Thorup-Kristensen, 1998b; Thorup-Kristensen, 1998a).

	Oil radish	Green pea	S. barley	Grass	Clover
Penetration rate (cm/day/°C)	0.23	0.09	0.1	0.08	0.1
Soil temp. penetration limit (°C)	0	0	0	0	0
Maximum effective root depth (m)	1.6	0.6	1.0	1.1	1.0

Of the various catch crops studied at Aarslev, data from the treatments *Oil radish*, *Italian ryegrass* and *No catch crop* were used to evaluate the model simulations. The catch crop modules were parameterised in DAISY with measured root growth parameters, see Table 3 (Thorup-Kristensen, 1997; Thorup-Kristensen, 1998b; Thorup-Kristensen, 1998a). Furthermore, for the Oil radish module, calibration on the data showed that the N-uptake per unit root length had to be increased by 50% and the photosynthetic efficiency by 20% compared to the spring rape values on which the module was based, the lower limit of temperature influence on photosynthesis was set to 1°C, and plant death set to initiate at 1 February. The green pea crop was modelled with a fodder pea crop module, modified only by decreasing the end-N-concentration by 40%.

The present version of DAISY is not able to simulate mixtures of monocots and dicots, i.e. grass-clover, simultaneously. Therefore, it was decided to use the default grass module in case of full year green fallow legume-grass (with an N input corresponding to the estimated N fixation) and to use the default clover module in case of autumn only legume-grass green manure. The same was the case for the grazed pastures at the Foulum site, where the year preceding the incorporation of the sward was simulated with the default grass module and a corresponding N input.

Table 4 Quantity and quality of the pasture plant residues (top+roots to 20 cm) incorporated at the Foulum site in early April 1997.

Grass type and usage	Dry matter incorporated* (t DM ha^{-1})		Total C (kg ha^{-1})	Total N	Total C/N ratio	Lignin (% of ash free DM)	Cellulose (% of ash free DM)	Water soluble C (kg ha^{-1})	Water soluble N	Water soluble C/N ratio
Grass-clover, cut	7.3	± 0.8	2462	150	16	11	21	542	33	16
Grass-clover, grazed	9.7	± 1.1	3522	247	14	9	20	352	59	6
Ryegrass, cut	14.0	± 1.9	4474	227	20	12	21	716	57	13
Ryegrass, grazed	11.8	± 1.1	4449	243	18	16	19	489	63	8

*: ± std.dev.

At the Foulum site, the amount of grass-clover plant residues in the different treatments was determined by sampling of cores to 20 cm depth immediately before sward incorporation. Aboveground herbage was separated and below-ground roots washed from the soil. Total C, N, cellulose and lignin was determined on all fractions (Table 4). From another set of plant residue samples, not separated by washing, an estimate of the water soluble C and N content of the plant residues was obtained (on average 16% of the C and 25% of the N, Tinghuis, unpublished results). These values were used to parameterise the initial amount and quality of grass-clover residue input.

Results and discussion

Aarslev site - stockless organic crop rotation

The modifications to the crop and catch crop modules mentioned above enabled us to simulate the plant dry matter production and N uptake satisfactorily for both fields throughout the cropping sequence, see Figure 1 for an example. In some cases barley dry matter production was underestimated. This may reflect the specific growing conditions in an organic crop rotation without any supply of external mineral N.

That it was necessary to increase parameters controlling the N-uptake (uptake per unit root length, photosynthetic efficiency) of the Oil radish catch crop plant notably (as described above and in Table 3), in order to fit the simulated Oil radish plant growth and N uptake to measured values, underlines the strong ability of Oil radish to take up residual mineral nitrogen remaining in the soil after a main crop.

Further work is clearly necessary on the simulation of the grass-clover, both as a full year "green manure" and as an autumn only green manure. As mentioned earlier, the present version of DAISY is not able to simulate monocot and dicot plant mixtures simultaneously. However, this problem may be solved in a new version of DAISY, which will be released shortly. As an alternative solution a "grass-clover"-plant module may be developed that is able to represent this plant mixture reasonably well.

The model's ability to simulate soil N dynamics appropriately in a cropping system with catch crops comprises several criteria, namely appropriate simulation of i) the catch crop biomass production and especially root growth, and thus soil mineral N depletion, ii) distribution of mineral N in the soil profile in the autumn and thus the leaching loss of nitrate N and iii) the mineralisation-immobilisation of incorporated catch crop residue N during the growing season. A comparison of measured and simulated soil mineral N distribution with depth in the soil profile (Figure 2) shows that the model accomplish the first and second criteria to a reasonable degree.

The simulated N mineralisation during spring (Apr-May) seems slightly underestimated in Figure 2, but in reality the temporal pattern of N mineralisation (data not shown) reveals that it is more a question of timing and in some cases distribution between the deeper soil layers. The setup used for the turnover of added soil organic matter was created for an investigation with rape straw incorporation (Mueller *et al.*, 1997). The rape straw represented typical mature plant residues with a relatively high C/N-ratio and a high content of recalcitrant components. The latter resulted in a model setup with very low substrate utilisation efficiencies. However, the green manure plants used here had a relatively high N-content and a high content of easily decomposable components. The low substrate utilisation efficiencies lead to a relatively high N mineralisation once the catch crops were incorporated. The same effect seems to be visible after incorporation of pea crop residues when not followed by a catch crop. With the same setup, Mueller *et al.* (1998) found discrepancies between measured and simulated soil mineral N after field incorporation of chopped grass and maize plants, an observation that has been confirmed by Thorup-Kristensen & Nielsen (1998). As a consequence, the concept of a general calibration of the added organic matter turnover for all materials must be questioned.

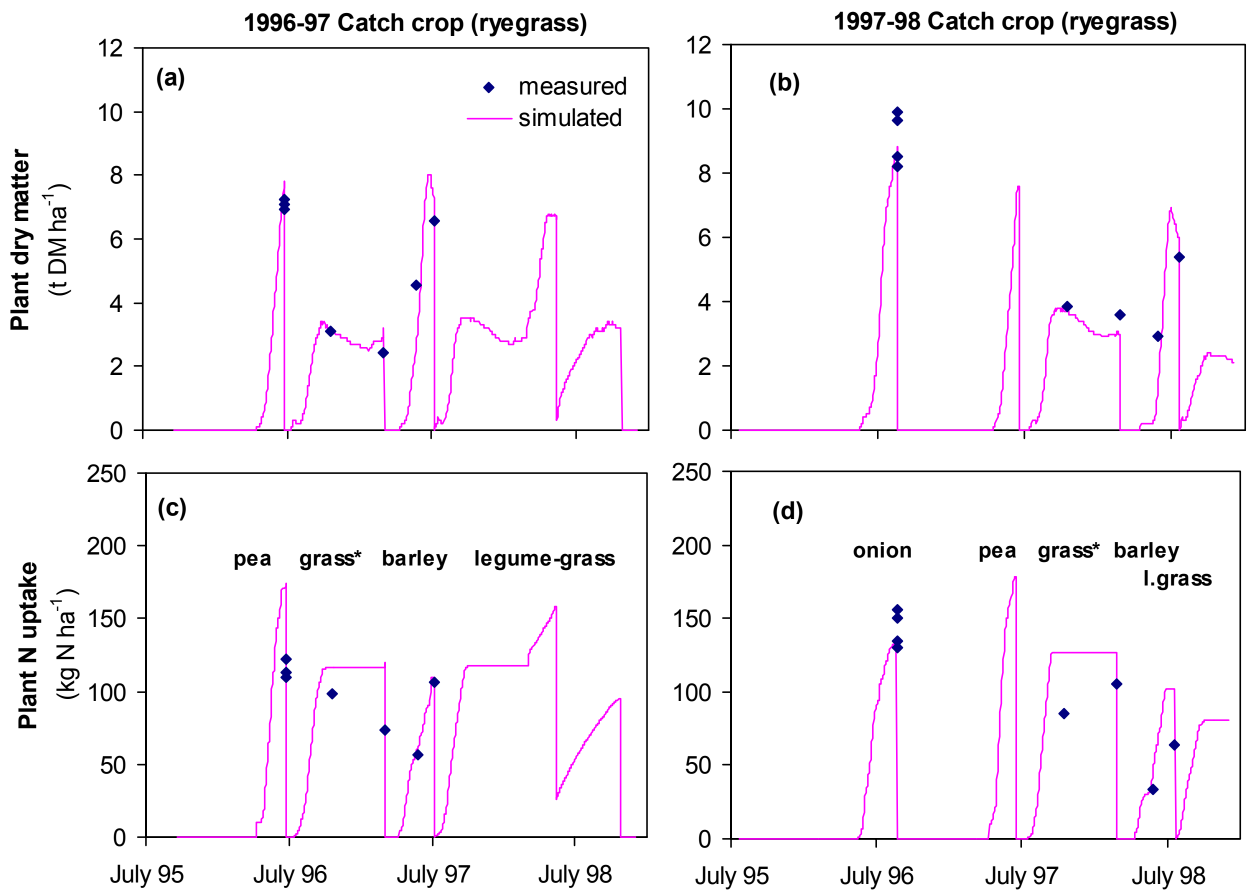

Figure 1 Measured (points) and simulated (lines) values of plant shoot dry matter production (a, b) and measured values of plant shoot N uptake and simulated plant total N uptake (c, d) in two fields with the green pea-ryegrass catch crop sequence in 1996 or 1997 of the Aarslev stockless organic crop rotation. *:Italian ryegrass was sown as a catch crop after the green peas were harvested in mid July.

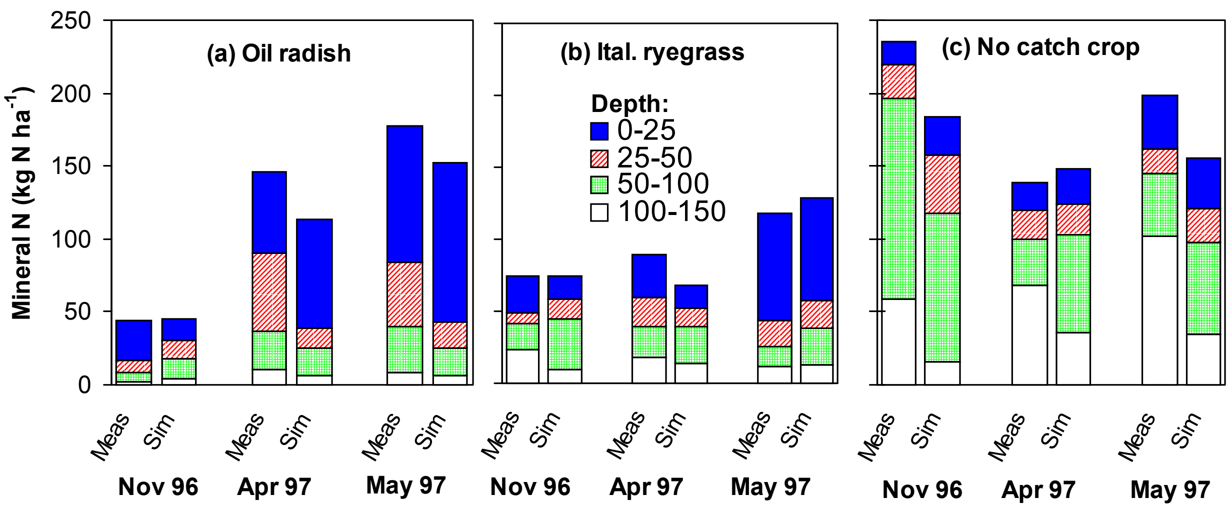

Figure 2 Measured and simulated values of soil mineral N in 0-25, 25-50, 50-100 and 100-150 cm depth under Oil radish (a), Ital. ryegrass (b) or no catch crop (c) of the Aarslev stockless organic crop rotation in autumn 1996 and spring 1997. Oil radish and Italian ryegrass were sown as catch crops after the preceding green peas were harvested in mid July

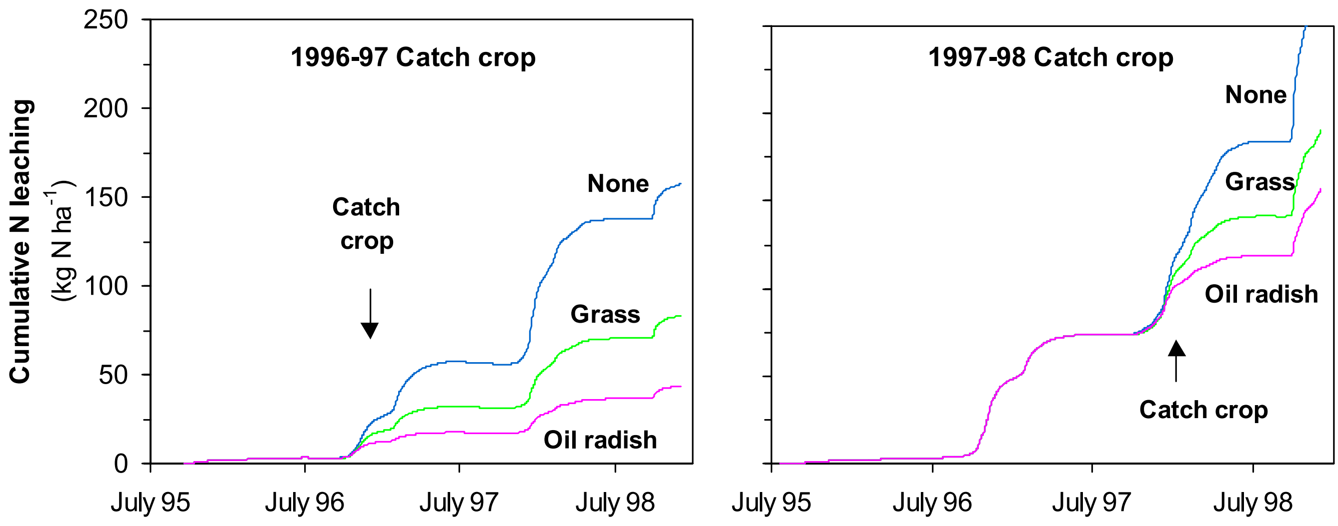

Figure 3 Simulated N leaching below 150 cm depth under Oil radish, Ital. ryegrass or no catch crop, in the 1996-97 and 1997-98 catch crops experiments of the Aarslev stockless organic crop rotation. Oil radish and Italian ryegrass were sown as catch crops after the preceding green peas were harvested in mid July.

Since the model seems to estimate the soil mineral N profile in the autumn reasonably well for the three treatment included here (Figure 2), we may assume that the simulated N leaching, for which we have no measurements to validate against, is fairly reliable as has been shown by others (e.g. Hansen *et al.*, 1991a; Svendsen *et al.*, 1995). The model simulations presented here show clearly that oil radish and grass had an effect on N leaching (Figure 3) and N-uptake of the following main crops. An Italian ryegrass catch crop reduced N-leaching by about 50%, and Oil radish reduced N-leaching about 75% compared to the situation with no catch crop. The effects of the N uptake on the yields of the following main crops depended on the specific year (data not shown). In both simulations, the catch crops increased the N-uptake of the following main crops. However, only in one of the simulated years the N uptake of the main crops differed depending on the preceding catch crops. The effects of the catch crops on N leaching were visible during the growth of the catch crops and during the following two growing seasons, where especially following the 1996/97 catch crop, the effect on second year N leaching is significant, with much higher mineral N losses below 150 cm where no catch crop had been grown the previous winter (Figure 3).

When the model has been tested and validated on the full crop rotation, we will be able to better estimate the effect of including a large proportion of catch crops and green manures on subsequent crop productivity and N recycling. Especially the effect of omitting catch crops in a few years in such rotations may prove problematic for N leaching losses.

The Foulum site - organic dairy crop rotation

Compared to the simulation of catch crop and annual green manures, the simulation of C and N mineralisation from grazed, perennial pastures represents a much more difficult challenge, since the input of organic matter and N is not well defined in time or space. If model simulations are to be of general predictive value, parameterisation of organic matter inputs, such as crop residues of a grass-clover sward, should be based on measurable properties. An important question is though: do we know the critical and measurable parameters for proper prediction of N mineralisation and subsequent crop utilisation under field conditions?

Our first approach, which we report on here, has been to parameterise the model for the grass pasture residues on the basis of the measured properties given in Table 4. The quantities of dry matter and N incorporated in above and below ground residues varies between ca. 7 to 12 t ha^{-1} and 150 to 250 kg N ha^{-1}, respectively. There is significantly more dry matter accumulated in the pure ryegrass treatments, and a slight tendency for total C/N-ratios to be higher for ryegrass compared to grass-clover, and for cut compared to grazed management. However, differences in C/N-ratio, lignin and cellulose contents between the treatments are not very large and for the latter do not indicate any clear trend. The water-soluble fraction contains a significant proportion of both C and especially N, but is noteworthy that the cut treatments C/N-ratio in this fraction was approximately twice as high as in the grazed treatments.

Spring barley yields in all the pasture treatments except the cut ryegrass, ranged between 4.6 to 5.4 t grain DM ha^{-1} with very small extra yield from the cattle slurry amendment of 124 kg NH_4-N ha^{-1}. Spring barley following the cut ryegrass yielded only 3.2 t grain DM ha^{-1} without slurry application. In comparison, the unfertilised reference plot yielded 2.5 t grain DM ha^{-1}. The model was capable of simulating the correct range in plant aboveground biomass production and plant N uptake as illustrated for the five treatments in Figure 4. However, the ranking of plant biomass production and N uptake differed greatly between measurements and simulation (Simulated: GCG=RG>RC>GCC>C and measured: GCC>GCG=RG>RC=C) and was probably due to the fact that the parameterisation of the grass residue input based on measured properties (Table 4) was not appropriate. It is interesting, that the only treatment which did not have a markedly positive effect on measured barley yields, the cut ryegrass with no slurry amendment (RC), was also the treatment containing one of the largest amounts of C and N in grass residues (Table 4), even with a reasonably low C/N ratio (20). The measured quantities were somewhat higher than in other studies (e.g. Høgh-Jensen & Schjoerring (1997), but not unrealistically high and they were confirmed by quantities measured in the field in a different study (Tinghuis, unpubl. results). The conclusions made for the Aarslev simulations, that substrate utilisation efficiency of added organic matter may be too low, is also highly valid here and supported by the results of de Neergaard *et al.* (1999). Furthermore, not much is known about the amount of N deposited in the form of e.g. root turnover or rhizodeposition during the growth of grass-clover pastures; even less is known about the effect of grazing intensity. It is evident, however, that in the further simulation work alternative approaches must be tested.

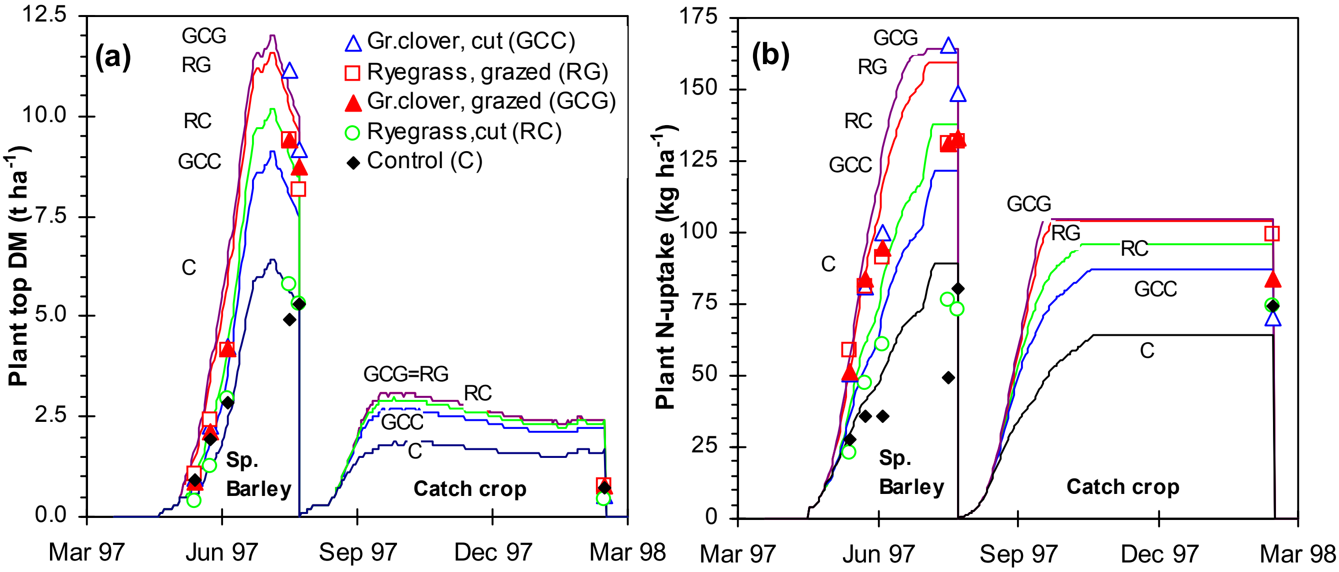

Figure 4 Measured (points) and simulated (lines) values of plant top dry matter production (a) and plant total N uptake (b) of spring barley and subsequent catch crop (ryegrass) in the 4 grass swards and the reference treatments with no fertiliser or manure N applied in the Foulum experiment. Abbreviations next to lines serves to identify simulated treatments (see legend).

The simulated N mineralisation from the pasture residues resulted in a reasonable simulation of soil mineral N content of the soil profile in the autumn (data not shown). However, when additional slurry was applied at the time of sowing the spring barley (Apr. 1997), a large overestimation of soil solution nitrate N content at 100 cm occurred during the following leaching period (Sept. 97 - Mar. 98, see Figure 5) when comparing with the only somewhat increased values measured in soil solution sampled with the ceramic cups. This led to a great overestimation of nitrate leaching (Sept. 97 - Mar. 98) in the treatments with the high amount of slurry amendment, e.g. for the grazed ryegrass + slurry treatment shown in Figure 5, the measured leaching was 57 kg N ha^{-1} and the simulated leaching 158 kg N ha^{-1}. The ceramic suction cup methodology used for determining soil solution nitrate has been questioned (Hatch *et al.*, 1997), but on this relatively sandy soil we do not believe this could be responsible for the large deviations between measured and simulated N leaching. Rather, part of the explanation could be the inappropriate parameterisation when based on the measured residue parameters as discussed earlier. Another part of the explanation could be that the simulated catch crop N uptake after the spring barley with slurry was underestimated by the model, but unfortunately we have currently no measured values to confirm this hypothesis. Additionally, an inappropriate simulation of mineral N turnover when such large amounts of slurry are applied on top of a high C and N mineralisation from the pasture swards, i.e. increases in denitrification or immobilisation, could also contribute to explain the large deviation between measured and simulated results in the slurry amended treatments.

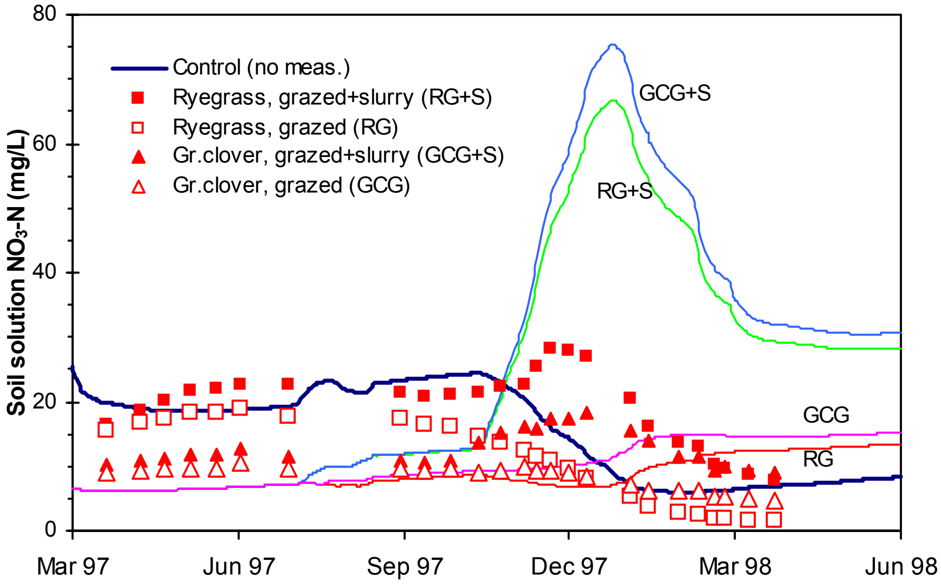

Figure 5 Measured (points) and simulated (lines) soil solution nitrate-N concentration at 100 cm depth in the Foulum experiment following incorporation of the grazed ryegrass and grass-clover pastures (with 0 or 124 kg slurry NH_4-N ha^{-1} applied in April 97) and in the reference field with no fertiliser N (only simulated values). The pastures were incorporated in early April 1997. Abbreviations next to lines serves to identify simulated treatments (see legend).

Conclusions

This study has confirmed the importance of thoroughly validating model performance on severl variables against measured data, before applying the model to cropping systems different from the ones it was developed for. It has also shown that the DAISY model is capable of modelling crop production in organic crop rotations, although more specific crop modules may have to be calibrated and there is a strong need for a robust crop module for grass-clover mixtures. The present results clearly indicate that the on-going simulation work will enable the use of the DAISY model as an analysis tool for evaluating the sustainability, productivity and environmental impact of organic crop rotations.

Acknowledgements

This study was financed by the Research Centre for Organic Farming 1996-1999 within tasks II.1 and III.1 of the NICLEOS project.

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Nutrient availability

The sulphur balance of organic crop rotations in Denmark

J. Eriksen[1], M. Askegaard[1], J.E. Olesen[1] and K. Thorup-Kristensen[2]
Danish Institute of Agricultural Sciences
[1]Dept. of Crop Physiology and Soil Science, PO Box 50, 8830 Tjele, Denmark
2Dept. of Fruit, Vegetable and Food Science, PO Box 102, 5792 Aarslev, Denmark

Summary

Significant reductions in SO_2 emission have been achieved in large areas of Europe as a result of national policies to reduce concentrations of primary air pollutants. The reduction in atmospheric deposition has resulted in a negative sulphur balance in many agricultural soils. Thus, in recent years there has been an increase in the frequency of S deficiency in Denmark in conventional crops. Sulphur deficiency affects crop yields and quality by decreasing the fraction of the S amino acids methionine and cysteine in the plant material. This decrease in the S amino acid concentration reduces nutritional quality when crops are used in human or animal nutrition, and it also affects physical properties such as the baking quality of wheat.

The S balance includes inputs in organic fertiliser, irrigation and atmospheric deposition and outputs in plant materials and as leaching losses of sulphate. The inputs and outputs were determined in a dairy rotation and a cereal-rich crop rotation (repeated on three sites). Furthermore, the S-uptake of a range of vegetables was determined. Short and long term consequences for yield and quality of organic food and fodder products is discussed on the basis of the S balances.

Introduction

As a part of the amino acids cysteine and methionine S influences the protein synthesis of plants. If the availability of S is insufficient the content of the amino acids in protein decreases or the protein synthesis stops (Eppendorfer, 1971; Eppendorfer & Eggum, 1994; Mortensen & Eriksen, 1994). Lowering the content of S in protein affects the nutritional value since methionine often is a limiting essential amino acid in diets, where cereal grains constitute the main source of protein (Marschner, 1990). Furthermore the baking quality of wheat is affected because the S amino acids in the gluten fraction of flour are responsible for the elasticity of the dough and the bread volume (Moss *et al.*, 1981; Wrigley *et al.*, 1984). Therefore insufficient S supply influences both the quantity and the quality of protein in plants.

Until 10 years ago S did not receive much attention in Danish agriculture because the atmospheric deposition, primarily originating from the burning of fossil fuels, exceeded the plant S demand. However, significant reductions in SO_2 emissions have been achieved in large areas of Europe as a result of national policies to reduce primary air pollutants. The S deposition has decreased from approx. 38 kg S ha^{-1} yr^{-1} in the late 1960'ies (Jensen, 1967) to approx. 12 kg ha^{-1} yr^{-1} in 1991-1992 (Hovmand *et al.*, 1994). As a result the overall S balance for Danish agricultural soils has been negative since the end of the 1980'ies (Eriksen, 1997). In certain years S deficiency symptoms has been widespread and the

Advisory Service has recommended S application in most crops. In organic farming systems we have only recently paid attention to the S supply of plants. This paper summarises the preliminary results of different investigations focussed on the S status of plants in different organic farming systems.

Materials and methods

The S balance includes inputs in organic fertiliser, irrigation and atmospheric deposition and outputs in plant materials and as leaching losses of sulphate. The inputs and outputs were determined in a six-year dairy/crop rotation (barley – grass-clover – grass-clover – barley/pea/ ryegrass – winter wheat – fodder beets) at Foulum from 1994-98 (described in Eriksen *et al.*, 1999) and in a cereal-rich crop rotation (barley – grass clover – winter wheat – barley/pea) at three sites (Foulum, Jyndevad and Flakkebjerg). Furthermore, the S-uptake of a range of vegetables was determined in experiments at Aarslev, where also investigations were carried out on the effect of catch crops on soil sulphate retention.

For the determination of sulphate leaching ceramic suction cups were installed before experiment start at a depth of 1 m. The water balance was calculated using the model EVACROP (Olesen & Heidmann, 1990). Sulphate leaching was estimated using the trapezoidal rule (Lord and Shepherd, 1993) assuming that sulphate concentrations in the extracted soil water represented average flux concentrations.

Results and discussion

The dairy/crop rotation

The S balance for the dairy crop rotation is shown in Table 1 (from Eriksen & Askegaard, 1999). Volatilisation from crops or soil was ignored as the amount of S emitted from these sources was considered insignificant (Janzen & Ellert, 1998). Inputs through irrigation water was 9.5 kg S ha^{-1}, which was 44% of the total-S input. Compared with the S removal in plant material of 9.8 kg S ha^{-1} the input through irrigation was significant. When including the contribution from atmospheric deposition estimated from Hovmand *et al.* (1994) the overall S balance becomes positive. Considering that inputs through irrigation and atmospheric deposition clearly exceed the S uptake by plants, it is not surprising that sulphate leaching is a major S output (on average 66% of total S output).

Table 1 S-balance of dairy/crop rotation at Foulum. Average of the growth seasons 1994-97 and of organic fertilizer treatments (kg S ha^{-1}).

	Barley	1^{st} yr grass-cl.	2^{nd} yr grass-cl.	Barley/ pea	Winter wheat	Fodder beets	Ave-rage
Input							
Atmospheric dep.*)	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Animal manure	17.3	0.0	5.5	4.8	18.6	27.1	12.2
Irrigation	10.2	17.1	16.7	3.3	10.0	0.0	9.5
Output							
Plant material	9.1	6.2	6.6	11.8	10.4	14.7	9.8
Weight gain cattle	0.1	0.7	0.8	0.0	0.0	0.0	0.3
Leaching	24.6	24.3	20.6	15.3	15.7	19.8	20.0
Balance	4.7	-3.1	5.2	-8.0	13.5	3.6	2.6

*) Estimated from Hovmand *et al.* (1994)

As an average of the years 1994-97 sulphate leaching from the crop rotation was 20 kg S ha^{-1} yr^{-1}, which was equivalent to 60% of the total input to the rotation. Sulphate leaching was very variable, ranging from 4 to 45 kg S ha^{-1} yr^{-1} for the same crop in different years. Thus, it is very important to have an estimate for sulphate leaching when using a mass balance approach for determining the S status of a crop rotation or a farm, especially for soils in temperate regions with high winter rainfall and with a low sulphate retaining capacity.

Cereal-rich crop rotation

The S balances for the cereal-rich rotation located at three sites are shown in Table 2. At all sites the output in plant material was very low, in average below 3 kg S ha^{-1}. This was caused by a combination of crops with a generally low S demand and low yields. Considering an atmospheric input of 11 kg S ha^{-1} it is very unlikely that any of these crops will experience S limitation, especially on the sandy soil were irrigation made a huge contribution to the pool of plant-available S in the soil.

Table 2 S-balance for the same cereal rotation at three sites in 1997-98 (kg S ha^{-1}),

		Barley	Grass-clover	Winter wheat	Barley/pea	Average
Jyndevad (sand)	Input					
	Atmospheric dep.	11.0	11.0	11.0	11.0	11.0
	Animal manure	3.1	0.0	3.1	0.0	1.6
	Irrigation	31.0	22.7	27.7	26.3	26.9
	Output					
	Plant material	3.4	0.0	2.3	5.4	2.8
	Leaching	40.6	46.7	44.8	47.8	45.0
	Balance	1.1	-13.0	-5.3	-15.9	-8.3
Foulum (loamy sand)	Input					
	Atmospheric dep.	11.0	11.0	11.0	11.0	11.0
	Animal manure	5.1	0.0	4.8	0.0	2.5
	Irrigation	0.0	0.0	0.0	0.0	0.0
	Output					
	Plant material	3.6	0.0	3.3	5.8	3.2
	Leaching	34.9	35.8	41.1	39.5	37.8
	Balance	-22.5	-24.5	-28.5	-34.3	-27.5
Flakkebjerg (sandy loam)	Input					
	Atmospheric dep.	11.0	11.0	11.0	11.0	11.0
	Animal manure	14.8	0.0	20.7	0.0	8.9
	Irrigation	0.0	0.0	0.0	0.0	0.0
	Output					
	Plant material	3.8	0.0	3.9	3.5	2.8
	Leaching	40.9	24.6	38.3	63.3	41.8
	Balance	-18.9	-13.6	-10.5	-55.8	-24.7

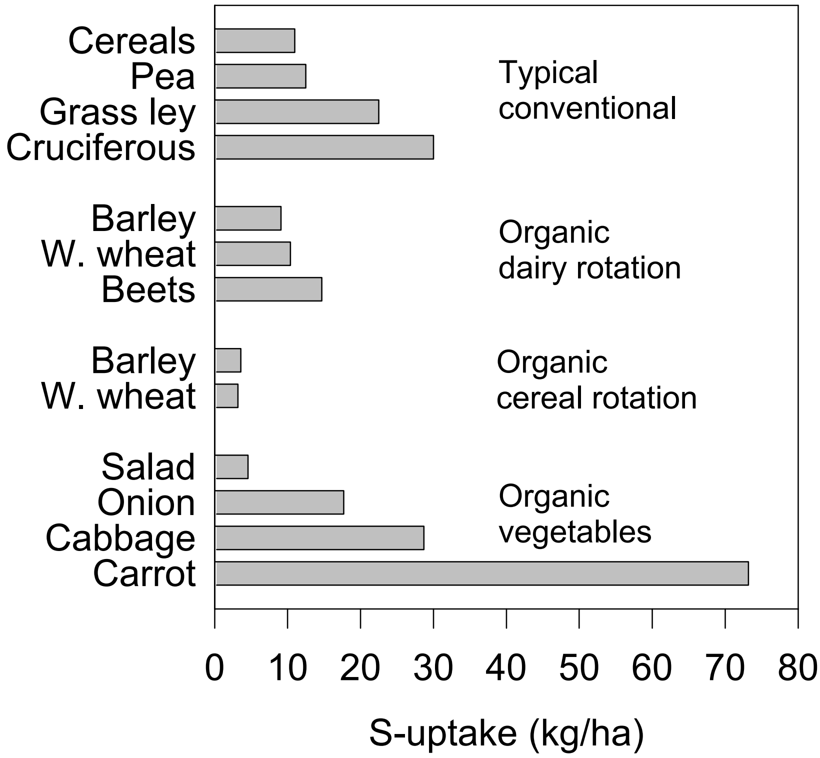

Figure 1 Sulphur uptake in different crops.

Leaching losses were high and exceeded the S inputs in all cases. Even though differences in drainage volume were large (average 680, 330 and 220 mm at Jyndevad, Foulum and Flakkebjerg, respectively) leaching losses were similar at the three sites. Also, the input of sulphate differed a lot. In Jyndevad the input of potentially leachable S was 27 kg S ha^{-1} higher than at the other locations and still leaching losses were about the same.

Leaching losses much higher than the S inputs to the rotation must be a consequence of the prehistory of high atmospheric deposition and S in commercial fertilizer. This rotation was converted to organic farming in 1996. In the dairy/crop rotation at Foulum leaching losses were lower in 1997-98 (average 25 kg S ha^{-1} yr^{-1}). This may be caused by a longer history of organic farming going back to 1987.

S-uptake in vegetables

The S-uptake of different crops is illustrated in Figure 1. Typical values for conventional farming is in the range of 10-30 kg S ha^{-1}; lowest for cereals and highest for cruciferous crops like oilseed rape. The S-uptake in organic grown cereals in the dairy crop rotation was similar to conventional grown cereals, whereas in the organic cereal rotation the uptake was lower.

Some vegetables have high S-uptake, especially spring cabbage and carrot. From a qualitative viewpoint high S content can be considered favourable because it enhances the taste of vegetables, making them spicier (Marschner, 1990). Sulphur deficiency in vegetable production needs further attention to avoid depletion of S in such systems leading to decreased quality.

Possibilities for improved S efficiency in organic farming systems

In order to maintain a sufficient S supply in the future when the expected further reductions in the atmospheric deposition, it is important to reduce leaching losses of sulphate. It has been demonstrated that a catch crop succeeding the main crop can absorb nitrate from the root zone during autumn and winter and thereby reduce nitrate leaching (Thorup-Kristensen & Nielsen, 1998). Similar beneficial effects of catch crops on sulphate leaching may be expected, and we are currently investigating this possibility. Figure 2 shows the content of soil sulphate at various depths under different catch crops grown after harvest of green peas in July 1996. In November 1996 it shows very clearly that the catch crops, especially the cruciferous fodder radish, were capable of removing huge quantities of sulphate from the soil solution, thus reducing the risk of sulphate leaching. As a consequence in the following spring (May 1997) after incorporation of the catch crop and sowing of barley the availability of sulphate in the topsoil was much higher following fodder radish than following ryegrass and bare soil.

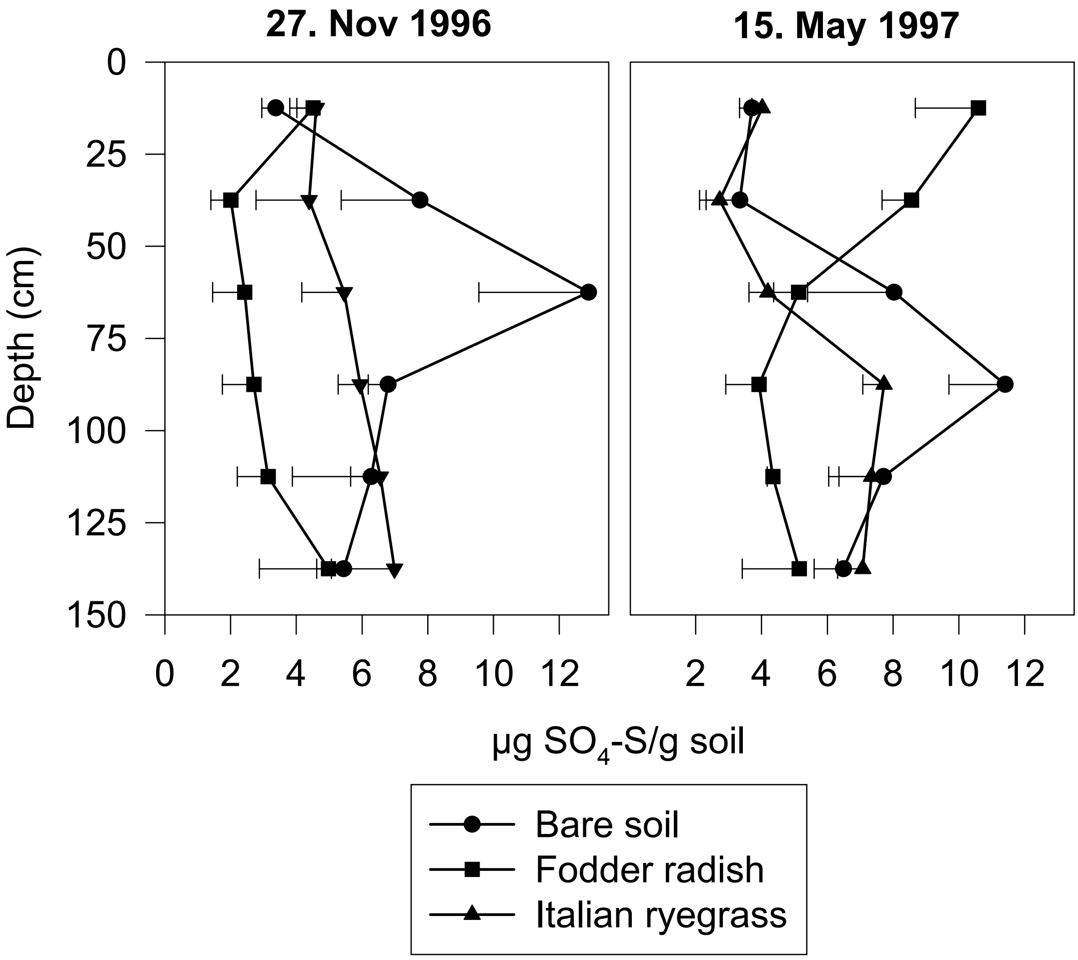

Figure 2 Sulphate concentrations in soil under different catch crops grown after harvest of green peas. Values represent the 25 cm layer where the symbol is placed.

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Nutrient management and plant production in four organic dairy farming systems

Margrethe Askegaard[1], Jørgen Eriksen[1], Karen Søegaard[1] and Søren Holm[2]
[1]Department of Crop Physiology and Soil Science, [2]Department of Plant Protection
Danish Institute of Agricultural Sciences, P.O. Box 50, DK-8830 Tjele, Denmark.

Summary

Organic dairy farms are characterised by a high stability in the crop production based on a sound crop rotation and a high degree of nutrient recycling. In a dairy crop rotation we investigated the effect of four organic farming systems with different livestock densities and different types of organic manure on crop yields and nutrient cycling. The experiment was carried out from 1994 to 1997/98 in the following crop rotation: barley, 1st year grass-clover, 2nd year grass-clover, barley-pea, winter wheat, fodder beet. The results demonstrated a high stability in the crop production. No or only small differences between the treatments indicated a good buffering capacity of the crop rotation. Contrary to expectation, no difference was observed between the two fertiliser/housing systems with respect to yield. Neither did we find differences in nitrate leaching between the two fertiliser/housing systems. Only small differences in nitrate leaching were found between the two livestock densities. Dry matter yields were on average only 5% higher in the systems with 1.4 livestock units per hectare compared to the systems with 0.9 livestock units per hectare. There was a high nutrient uptake as a consequence of a high yield level and there was a low level of nitrate leaching of on average 38 kg nitrate-N ha^{-1} yr^{-1}. There were however large differences in nitrate leaching from the different crops with the highest loss in the second winter after ploughing in of grass-clover and the smallest loss in the 1st year grass-clover. Problems with weeds, diseases and pests were small. Nutrient balances for nitrogen (N), phosphorus (P) and potassium (K) were predominantly positive. Only in the systems with slurry and 0.9 livestock units per hectare would K be considered as yield limiting in the longer term. There were periods with K-deficiency symptoms in all four systems in the 2nd year grass-clover and in the succeeding barley/pea whole crop. K-deficiency was the possible reason for the unexpected increase in clover content in the 2nd year grass-clover when slurry was applied. Change of the crop rotation and better distribution of the organic manure in the crop rotation may improve nutrient utilisation and reduce nitrate leaching.

Introduction

Organic farms in Denmark are dominated by dairy farms. The primary reason for this is that dairy farms are easily converted to the organic farming system because of sound crop rotations with a high content of N_2-fixing crops and a high recycling of nutrients. Organic dairy farms are characterised by a high degree of stability in the crop production. Essential factors in this context are the sensitivity of yield and nutrient availability to changes in livestock density and type of animal manure. On the basis of this and with the organic dairy farming system as the unit, three hypotheses were formulated:

1. The yield in a crop rotation will decrease with decreasing livestock density.
2. The yield in a crop rotation is lower when deep litter is the nutrient source than when slurry is used, in comparisons of systems with similar livestock densities.
3. The N-utilisation in a crop rotation decreases with increasing livestock density resulting in higher N-leaching losses.

The hypotheses were tested in a field trial in the organic dairy/crop rotation located at Research Centre Foulum. The treatments were designed on the basis of four different organic dairy farming systems representing two livestock densities and two systems of cattle housing based on either slurry alone or a combination of slurry and deep litter.

Materials and methods

Location

The dairy/crop rotation is located at Research Centre Foulum in the central part of Jutland, Denmark (56°30'N, 9°34'E). The soil is classified as a Typic Hapludult with 7.7% clay and 1.6% carbon. The fields were converted to organic farming in 1987 when a six-year rotation was introduced replacing a conventional cereal rotation (Table 1).

Table 1 History of the dairy/crop rotation at Research Centre Foulum.

Period	Agricultural management system
1974-1986	Mostly cereals; straw removal; inorganic fertiliser
1987-1998	Organic dairy/crop rotation; Until 1994 cattle slurry (1-1.3 LU/ha)
	Barley undersown with grass-clover
	1st year grass-clover
	2nd year grass-clover
	Barley/pea/ryegrass (whole crop)
	Oats (1987-93) or winter wheat (1994-98)
	Fodder beet

Treatments

In autumn 1993 and spring 1994 four organic manure treatments with four replicates were established (Table 2), replacing the previous slurry application. The treatments represent two systems of cattle housing based on either slurry alone or a combination of slurry and deep litter at two livestock densities. The livestock densities were 0.9 and 1.4 livestock units (LU) per hectare. One LU is equivalent to 1 milking cow of a large breed. In the slurry system 1 LU corresponded to 114 kg total-N in manure, and in the combined system with deep litter and slurry 1 LU corresponded to 124 kg total-N in manure. The difference was caused by the straw-N content in deep litter.

Table 2. The four experimental treatments (1994-97). LU is livestock unit.

Manure type	LU/ha	Abbreviation
Slurry	0.9	0.9 S
Slurry	1.4	1.4 S
Deep litter + slurry	0.9	0.9DS
Deep litter + slurry	1.4	1.4DS

To ensure realistic conditions detailed feed and fertiliser budgets were made for each system. The amount of organic manure for application was calculated as total production minus manure excreted during grazing. The fertilization plan is outlined in Table 3. Organic manure was applied in spring on the basis of total-N content and incorporated into the soil immediately, or applied to growing plants using trail hose application. The difference between the 0.9 and 1.4 LU/ha systems was on average 40 kg of total-N (Table 3). In slurry, dry matter content was 6-8% and NH_4-N was 50-60% of total-N. In deep litter, dry matter content was 27-31% and NH_4-N was 2-21% of total-N.

Table 3 Organic manure application to the dairy crop rotation (kg total-N/ha).

		0.9S	1.4S	0.9DS	1.4DS
Barley, grass-clover	Slurry	70	100	0 (50)	50 (80)
undersown	Deep litter	-	-	175 (90)	175 (90)
1st year grass-clover	Slurry	0	0	0	0
	Deep litter	-	-	0	0
2nd year grass-clover	Slurry	70	140	0	0
	Deep litter	-	-	0	0
Barley/pea whole	Slurry	0	60	0	0
crop	Deep litter	-	-	0	90
Winter wheat	Slurry	140	170	130 (80)	170 (140)
	Deep litter	-	-	0 (90)	0 (90)
Fodder beets	Slurry	210	250	110	140
	Deep litter	-	-	110	160
Average		82	120	88	132

( ) Manure application in 1994. In the following years it was changed to avoid application of deep litter to winter wheat in the autumn.

Design and management

Each of the six fields in the rotation was divided into four blocks in which the treatments were randomly placed in plots of 15×18 m. Following 1st cut of herbage in mid June cattle grazed the grass-clover fields. The treatments with 0.9 and 1.4 LU ha^{-1} were grazed by two separate groups of heifers (average weight 446 kg). Barley mixed with pea and ryegrass was sown after spring ploughing of grass-clover and was harvested for silage in July/August. The stubble was ploughed in late September and winter wheat was sown. After harvest of winter wheat, the field was left undisturbed, except for 2-3 passes with a harrow for weed control, until the following spring when fodder beet was sown. The beets were harvested in October-November and the field left undisturbed until after spring ploughing when barley was sown with a mixture of white clover and ryegrass in order to establish the following grass-clover. Occasionally irrigation was used especially to maintain the grass-clover fields during summer.

Harvest yields were obtained from an area measuring between 36 and 108 m^2 depending on the crop. A Haldrup plot harvester was used for cereals and grass-clover, whereas fodder beet was removed by hand. Subsamples were taken for determination of dry matter and N content.

Before the experiment started, three ceramic suction cups were installed in each of the 96 plots at a depth of 1 m and spaced 2 m apart. Every one or two weeks, depending on precipitation, suction of approximately 80 kPa was applied three days prior to sampling. The samples were either analysed separately or bulked with equal sample volume from each of the three cups per plot before analysis.

The water balance was calculated using the model Evacrop (Olesen & Heidmann, 1990) for which inputs were daily meteorological measurements (precipitation, temperature and potential evapotranspiration) and crop type, time of sowing, cutting and irrigation and soil physical parameters. Nitrate leaching was estimated using the trapezoidal rule (Lord & Shepherd, 1993), assuming that nitrate concentrations in the extracted soil water represented average flux concentrations. The accumulated leaching was calculated from 1 April to 31 March.

Data was analysed by use of a simple analysis of variance. The amount of leached nitrate for all crops and years was analysed using a general linear model (Eriksen *et al.*, 1999). In the tables a letter follows the values. Values with the same letter are not significantly different ($P<0.05$). A detailed description of the experiment is given in Askegaard *et al.* (1999).

Results and discussion

Yields

As expected we obtained higher dry matter yields in the systems with 1.4 LU ha^{-1} compared to the systems with 0.9 LU ha^{-1}. However, the yield increase was small and only found in barley, barley/pea whole crop and winter wheat (Table 4). Contrary to expectation we did not find yield differences between the systems with slurry and the systems with a combination of deep litter and slurry.

Table 4 Yields (t DM ha-1) as average of 1994-1997 (2nd year grass-clover 1995-97). Yields in grass-clover are from 1st cut, after which the plots were grazed by cattle.

Treat-ment	Barley		1st year grass-cl.	2nd year grass-cl.	Barley/pea whole crop	Winter wheat		Fodder beets	
	Grain	Straw				Grain	Straw	Root	Top
0.9S	3.8^{c}	3.9^{c}	3.7^{ab} (4.4)	4.9^{a} (4.6)	8.1^{b}	5.0^{b}	4.7^{b}	11.2^{a}	3.2^{bc}
1.4S	4.2^{b}	4.1^{b}	3.7^{b} (4.7)	5.0^{a} (4.4)	9.1^{a}	5.2^{a}	5.1^{a}	11.1^{a}	3.4^{a}
0.9DS	3.7^{c}	4.1^{ab}	3.8^{ab}	4.5^{b}	8.0^{b}	4.8^{b}	4.6^{b}	11.2^{a}	3.1^{c}
1.4DS	4.4^{a}	4.3^{a}	3.9^{a}	4.3^{b}	8.8^{a}	5.3^{a}	5.2^{a}	11.4^{a}	3.3^{ab}

( ) Yields when slurry, in an additional experiment, was applied to the 1st year grass-clover instead of the 2nd grass-clover.

In the 0.9DS-treatment in barley, deep litter was applied solely resulting in a delayed N-uptake from the beginning of the growing period compared to the 0.9S-treatment where slurry was applied (results not shown). Despite this difference we did not measure any yield differences at harvest between the two treatments. The 2nd year grass-clover responded with a yield increase when slurry was applied in the 0.9S- and 1.4S-treatments compared to the 0.9DS and 1.4DS treatments. In an additional experiment it was shown that the yield increase could be more than doubled by moving the application of slurry from the 2nd to the 1st year grass-clover (Table 4). Contrary to the expectation there was a high response to manure application in the barley-pea whole crop. The reason for this high response was probably a combination of the timing of the N-release from the precrop (2nd year grass-clover) in combination with a K-deficiency in the crop. As an average of the four years we obtained a higher yield of winter wheat in the treatments with 1.4 LU ha^{-1} than in the treatments with 0.9 LU ha^{-1}. This was expected because winter wheat is the cereal crop with the highest N-demand (Lampkin, 1992). However, in two out of four years there was no significant yield increase when increasing livestock density from 0.9 to 1.4 LU ha^{-1}. The lack of response must be ascribed to the sensitivity of winter wheat, and is probably caused by a complex of factors such as soil water balance, timing of N-release from the precrop and from the manure and attack of pests and diseases. In fodder beets there was no significant yield increase when manure application was increased from the 0.9 LU ha^{-1}-level to the 1.4 LU ha^{-1}-level.

The fertilisation plan could be improved with respect to yield increase by transferring some of the manure from the fodder beets to other crops in the rotation and a transfer of slurry from the 2nd year grass-clover to the 1st year grass-clover.

Nitrate leaching

The nitrate leaching as an average of treatments, crops and years was 38 kg N ha^{-1}. This is equivalent to a nitrate concentration in drainage water of 57 mg l^{-1}, which is close to the limit value of 50 mg l^{-1} in drinking water. No significant differences were found between the two manure systems and only a small difference of on average 6 kg N ha^{-1} yr^{-1} was found between the two livestock densities (Table 5). While the difference between the treatments was low, there were large differences between crops and years. Averaged over the four experimental years the nitrate leaching was highest, 61 kg nitrate-N ha^{-1} yr^{-}

[1], in the second winter following the ploughing of grass-clover. Nitrate leaching was lowest in 1st year grass-clover (20 kg N ha^{-1} yr^{-1}) (Table 6). There were large variations between years ranging from 4 kg N ha^{-1} yr^{-1} in 1995/96 to 67 kg N $ha^{-1}y^{-1}$ in 1997/98. The main reason were differences in drainage volume.

Table 5 Average nitrate leaching per treatment (kg N ha^{-1} yr^{-1}).

Treatment	Leaching
0.9S	34^{b}
1.4S	42^{a}
0.9DS	36^{b}
1.4DS	39^{a}
Average	38

Table 6 Nitrate leaching from crops each year as average of treatments (kg NO_3-N/ha). Values with the same letter are not significantly different within the column ($P<0.05$).

	1994-95	1995-96	1996-97	1997-98	Average
Barley	28^{c}	7^{b}	15^{c}	22^{c}	27^{e}
1st year grass-clover	17^{d}	2^{c}	13^{cd}	53^{bc}	20^{f}
2nd year grass-clover	83^{ab}	1^{c}	9^{d}	90^{ab}	28^{d}
Barley/pea-whole crop	77^{ab}	1^{c}	53^{a}	89^{a}	43^{bc}
Winter Wheat	87^{a}	5^{b}	44^{a}	80^{a}	61^{a}
Fodder beet	57^{b}	11^{a}	21^{b}	48^{b}	48^{b}
Average	57	4	24	67	38

All numbers are based on estimates from analysis on log transformed values. Therefore, the marginal means are not identical to the means of individual crop/year combinations.

The leaching losses were to a high degree related to the ploughing in of the grass-clover, and the largest losses were measured during the first three years after grass-clover. The reason for this is the high amount of crop residues left over from the grass-clover.

The crop rotation could be improved in order to minimise leaching losses. Replacing the winter wheat with a spring cereal and introducing winter growing catch crops in the two crops following the grass-clover would improve the capacity of the system to retain leachable nutrients.

N, P and K balances

Depending on the nutrient, the following factors were included in the field balances: Nutrient input in manure, irrigation water and seeds, and nutrient output in harvested material, leaching losses and in the weight gain of grazing cattle. The nutrient transport in seeds, irrigation and weight gain was, however, small compared to the transport in manure, harvested material and leaching. The total balance for the four treatments is shown in Table 7.

Table 7 Nutrient balances* based on measured factors (kg/ha) as an average of crop rotation and years (1994-1997).

Treatment	N	P	K
0.9S	-65	-1.0	-12
1.4S	-45	5.6	6
0.9DS	-56	1.4	-2
1.4DS	-23	9.1	30

*) The balances include inputs in manure, irrigation and seeds and output in harvested material and meat. Outputs in leaching is included only in the N-balances. N_2-fixation was not measured in all treatments and years and is therefore not included in the balances.

The N-balances were all negative. In addition to the measured factors, N-import through N_2-fixation and atmospheric deposition and N-export through gaseous losses must also be taken into consideration. By including estimates for these missing factors Eriksen *et al.* (1999) found a positive N-balance in all four treatments in the experiment, but it was concluded that the magnitude of the N-accumulation in soil organic matter is likely to be small.

Assuming a low level of P leaching of only a few hundred grams per hectare (Windolf, 1995), P will not be yield-limiting in the four systems in the near future. In the long term the slightly negative P-balance in the system with 0.9 LU ha^{-1} and slurry may accumulate and cause problems with P-deficiency.

The K-balances ranged from -12 kg K ha^{-1} in the 0.9 LU ha^{-1}-treatment to a surplus of 30 kg K ha^{-1} in the 1.4 LU ha^{-1}-treatment. In order to evaluate the long-term stability of the systems K-deposition and K-leaching losses must be included. The contribution of K from deposition is, however, only about 1.3 kg K ha^{-1} yr^{-1} (Hovmand *et al.*, 1994) and K-leaching was considered to be only a few kilograms per hectare (Askegaard *et al.*, 1999). In the long term K is considered to become yield-limiting in the 0.9 LU ha^{-1}-system.

Pests, diseases, weeds and nutrient deficiencies

There were no recorded differences between treatments in the occurrence of pests and diseases. The level of attack was predominantly low, and it was assumed that the yields were only little influenced.

The amount of weeds registered as percent of total dry matter (DM) in barley, barley/pea whole crop and winter wheat was moderate. As an average of years and at the start of July weeds constituted less than 6% of DM in barley, less than 12% of DM in barley/pea whole crop and less than 7% of DM in winter wheat. In barley/pea whole crop and in winter wheat there was a tendency towards a higher percentage of weed infestation in the treatments with 1.4 LU ha^{-1} compared to the 0.9 LU ha^{-1}-treatments. This tendency, however, disappeared later in the growing season. The fodder beets were kept totally free from weeds by mechanical and manual weeding. The grass-clover fields were nearly free from weeds.

In the project period potassium was the only nutrient for which we observed visual symptoms of deficiency. The symptoms were seen in the spring in barley, in the barley/pea whole crop and in clover in the grass-clover, especially in the 2nd year. These findings corresponded with the level of exchangeable K being lowest in the 2nd year grass-clover and in the barley/pea whole crop.

The stability and buffer capacity of the system

The four systems showed a high degree of stability. The stability becomes evident through the relatively high yield level and the limited problems with weed, diseases and pests in all four experimental years. The four systems also showed a high buffering capacity indicated by the lack of large differences in yields and N-leaching. The stability and buffering capacity can probably be ascribed to the combination of crops in the crop rotation and to the contribution of the grass-clover to soil fertility which includes the N_2-fixing ability and the weed and disease inhibiting qualities. On the timescale the grass-clover covered 40% of the rotation estimated from harvest of the barley cover crop to the ploughing in of the 2nd year grass-clover.

An important factor responsible for the assumed buffering capacity in the crop rotation is probably an N-regulating mechanism in the grass-clover fields which evens out differences in the N-balance. An argumentation for this postulate appears from the following: If we consider the N-balance (Table 7) and exclude the N-leaching losses (Table 4) we have a difference in the measured N-balance from -31 kg N ha-1 yr-1 in the 0.9S-system to +16 kg N ha-1 yr-1 in the 1.4DS-system corresponding to a difference of 47 kg N ha-1 yr-1. In balance calculations standard estimates for atmospheric deposition (14 kg ha-1 yr-1 (Grundahl & Hansen, 1990)), N2-fixation (82 kg N ha-1 yr-1 as an average of crop rotation (Eriksen et al. 1999)), NH3 emission and losses from denitrification from the grazed fields (5 to 10 kg N ha-1 yr-1 as an average of crop rotation (Eriksen et al. 1999) and from the manure application may be included. These estimates will, however, probably not result in large changes of the total differences in N-balance between the four systems. As missing factors we now have the contribution from leaching losses and N-accumulation in soil organic matter. Based on the 47 kg N ha-1 yr-1 difference in N-balance, the leaching of N would be expected to be much higher in the 1.4DS-system than in the 0.9S-system. This was however not the case, as the measured difference only amounted to 5 kg N ha-1 yr-1 between these two systems. We now have the N-accumulation in the soil showing differences of up to 42 kg N ha-1 yr-1 between the 1.4DS- and the 0.9S-system, and this does not seem realistic. The differences in the basic N-balance is probably, to a certain degree, evened out by a lower N-input through N2-fixation activities and a higher ammonia emission and denitrification in the 1.4 LU ha-1-system compared to the 0.9 LU ha-1-system.

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Optimising phosphorus and potassium management for crop rotations in UK organic farming systems

S. Fortune[1], E.A. Stockdale[1], L. Philipps[2], J.S. Conway[3], J.S. Robinson[4] and C.A. Watson[5]
[1] Department of Soil Science, IACR-Rothamsted, UK
[2] Elm Farm Research Centre, UK
[3] The Royal Agricultural College, UK
[4] Department of Soil Science, The University of Reading, UK
[5] Land Management Department, SAC (Aberdeen), UK

Summary

Successful organic farming systems rely on the efficient use and cycling of phosphorus (P) and potassium (K) within the farm. P and K management decisions are made for the rotation or system as a whole. As organic farmers are encouraged to minimise their use of external inputs, the redistribution and efficient use of manure and beneficial land management practices, such as ley arable rotations, is critical. In order to understand the impact of management practices it is necessary to understand the inputs, internal cycling and outputs of P and K from the farming system. This paper will present information on P and K budgets for organic farming systems and soil P and K data from a survey of organically farmed soils. A combination of soil analysis and budget approaches can help farmers to make scientifically and economically sound management decisions, allowing the sustainable use of P and K while requirements of organic farming are met at least risk to the environment.

Introduction

The economic and environmental sustainability of organic farming is dependent on the efficient use of phosphorus (P) and potassium (K). As farming systems can never be completely closed due to sales of produce and losses to the environment it is necessary for nutrients to be replaced in order to maintain soil fertility. P and K enter the farming system through stock purchases, bought in feed, seed, rain and dry deposition, with feed representing a major source of nutrients within organic farming systems. Where there are still nutrient deficits, P and K may also be brought onto the farm in manure, straw and approved fertilisers. However, the emphasis of organic farming is to encourage the efficient cycling of nutrients rather than rely on P and K provided in fertilisers and purchased manure. P and K flows within mixed organic farming systems have both a temporal and spatial aspect, with P and K applications made strategically within the rotation, and with manure and slurry used to redistribute nutrients around the farm (Figure 1).

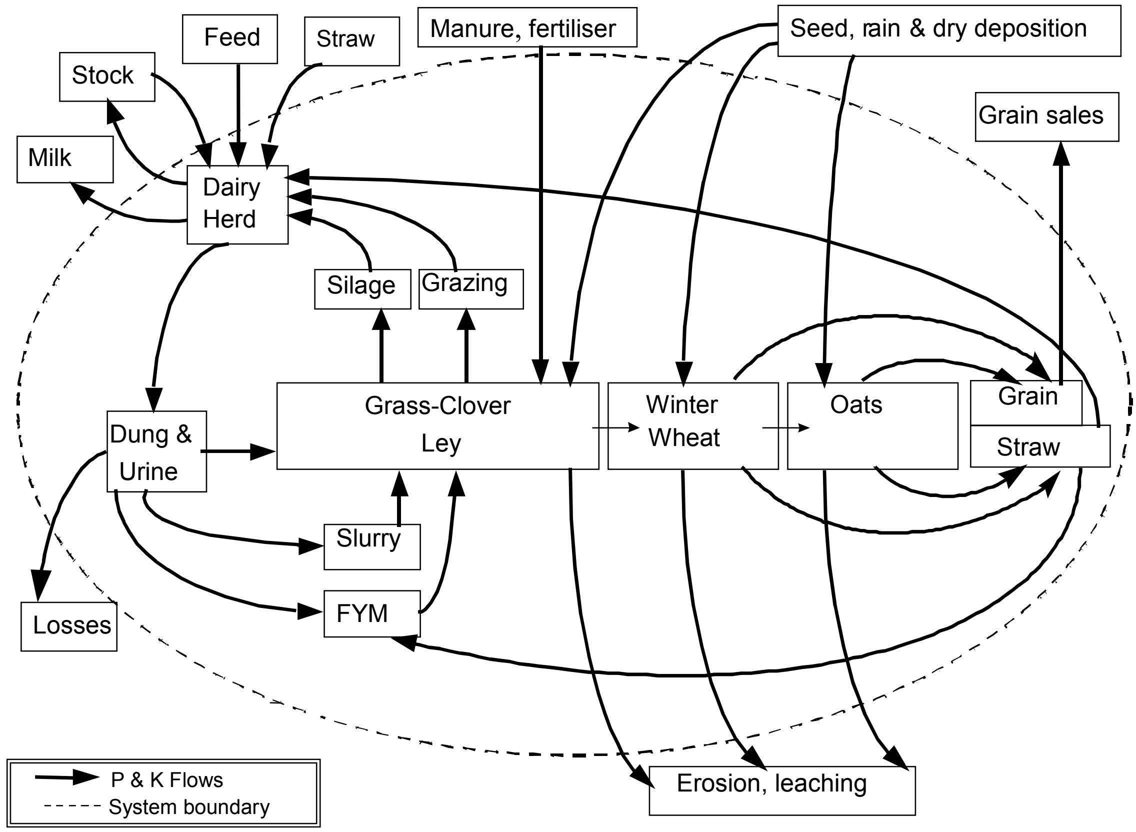

Figure 1 P and K flows for a mixed organic farm.

Nutrient budgets provide a useful means of studying farming systems by providing a breakdown of nutrient inputs and outputs and, in more comprehensive studies, a quantification of internal flows (Watson & Atkinson, 1999). This information, combined with an index of P and K availability, can give an indication of the sustainability and agronomic efficiency of the farming system. Nutrient balances for organic farms will also be useful in answering questions on whether organic farmers are mining soil P and K pools. The outputs in terms of nutrient balances are also helpful in optimising the management of these systems and preventing or mitigating negative environmental impacts.

Materials and methods

Soils in England and Wales are routinely analysed for available P using Olsen-P (Olsen *et. al.,* 1954) or ammonium acetate extraction, and for available K using ammonium nitrate (Rowell, 1995) or ammonium acetate extraction (Metson, 1965). Soils can be grouped into categories from zero to nine, the soil index (Tables 1 and 2). The soil P and K index is then used to indicate potential crop deficits, the likelihood of crop response to new P and K additions and to plan fertilisation strategies.

Table 1 Soil P indexes (ADAS). Source: MAFF RB209.

Available P P Index	Sodium bicarbonate extraction (Olsen) (mg/l)	Ammonium acetate – acetic acid extraction (mg/l)	Crop yield response to P additions
0	0-9	0-2	Probable
1	10-15	2.1-5	Possible
2	16-25	5.1-10	Unlikely
3	26-45	11-20	Unlikely
4	46-70	21-40	Unlikely
5	71-100	41-70	Unlikely

Table 2 Soil K indexes (ADAS). Source: MAFF RB209.

Available K K Index	Ammonium nitrate extractable K (mg/l)	Crop yield response to K additions
0	0-60	Probable
1	61-120	Possible
2	121-240	Unlikely
3	241-399	Unlikely
4	400-600	Unlikely

An alternative method for determining soil P is the sequential Balzer-P extraction (Balzer & Balzer-Graf, 1984). This procedure involves the extraction of P by three different solutions; 2% citric acid, double lactate, and sodium acetate and is thought to provide additional information on soil P by determining soil reserve, plant available and water soluble P, respectively. This method is routinely carried out on soils (pH<7) submitted to the UK Organic Advisory Service based at Elm Farm Research Centre. For arable cropping and grassland, acceptable levels of P and K to maintain productivity are between 100 and 300 mg P kg^{-1} soil and between 100 and 200 mg K kg^{-1} soil, respectively, extracted in the double lactate extraction (EFRC, 1999). Data for soils submitted for analysis to the Organic Advisory Service during 1997 were collated and compared with the compiled data of the P and K status of UK arable soils.

Nutrient budgets can be used alongside soil analysis to provide additional information on a farming system. Farm gate budgets are among the simplest form of nutrient budgets. These only deal with nutrients bought or sold over the farm gate, e.g. feed, stock, seed, milk and grain. Farm gate budgets for P and K were collated for a number of organic farms using farm records, measurements and standard tables of nutrient contents. The difference between the sum of inputs and the sum of the outputs gives the farm nutrient balance. If the inputs and outputs balance, the farming system is considered to maintain soil fertility, while a surplus of nutrients can provide an indication of the potential for increased environmental losses of nutrients, and a negative balance can raise questions of sustainability. The farm nutrient balance can also provide a guide to the efficiency with which imported nutrients are converted into produce (Watson & Stockdale, 1998).

The farm gate budget approach does not provide information on soil processes or biological inputs and outputs of nutrients, which are particularly important for N. For this, quantification of internal flows is needed. Measuring internal flows also provides information on changes in the forms of nutrients, such as feed to manure. These transformations may be associated with major losses from the system. The loss of K from manure heaps during storage has been found to be particularly high. The use of more complex budgets can therefore provide us with more information. However, as the complexity of the approach increases there is often a need to estimate increasing numbers of variables. The estimation of some of the nutrient flows can lead to large errors, the magnitude of which will be related to the importance of the variable that is estimated. However, because of the spatial and temporal nature of P and K cycling in organic farming systems (Watson & Stockdale, 1997), it is important to consider the internal flows and biological processes in addition to the inputs and outputs of P and K over the farm gate. An analysis of spatial flows can highlight the enrichment or depletion of nutrients from different parts of the farm. For example, the practice of spreading manure and slurry preferentially to fields nearest the manure stores can lead to preferential enrichment at the expense of other fields (Bacon *et al.*, 1990). Temporal flows are also important as P and K inputs are often made to the ley phase of the rotation and then released into plant available forms throughout the whole rotation. An average P or K balance for the farm may mask important differences between fields. The quantification of internal flows is also particularly important for organic farming because of the desire to maintain and improve internal recycling of nutrients (UKROFS, 1991). Overall, the use of a complex budget approach allows the impacts of farm management practices (rotations, cropping, manure management) to be examined in more detail. During this project we are developing a computer program to allow nutrient budgets, including internal flows, to be created more rapidly and easily and provide the facility for what-if scenarios to be run.

Results and discussion

The widespread use of fertilisers in conventional agriculture has seen a dramatic reduction in crop and animal nutrient deficiencies and a situation where most UK arable soils are well supplied with P and K (Tunney *et al.*, 1997). Organic farmers are often accused of simply mining soil supplies of P and K built up by historic fertiliser applications. With conversion to organic farming there is likely to be a significant drop in net P and K inputs to the farming system due to the lack of fertiliser and a reduction in supplementary feed imports. Where additional P and K inputs on conventional farms have ceased, a decline in soil P and K status has been found, the extent of the decline dependent on several factors including crop removal and soil type (Chalmers *et al.*, 1997). Loes & Ogaard (1997) found reductions in available P and K in soils with previously high levels following conversion to organic farming as a result of the reduction in net imports.

In a survey of arable soils under conventional farming, only 15% were recorded at a P Index of 0 or 1 (deficient) compared to 30% at Index 2 (adequate) and 55% at or above Index 3 (Figure 2). For K, 30% of the soils tested were at index 0 or 1, 50% at Index 2 and 20% at 3 or above (Figure 3). A different situation exists for grassland, with 20-25% of soils at a P Index of 0 (Chambers *et al.,* 1996). Although intensively managed grassland systems receive high inputs of fertiliser, 43 % of grassland in England and Wales receives no fertiliser (Burnhill *et al.,* 1993; Burnhill *et al.,* 1997). Although comprehensive data sets have been recorded for conventional farming, there are limited figures available for the P and K status of organically farmed soils. Data compiled from one year's analyses of soil samples from organic farms showed that 39% (Olsen-P) were at P index 0 or 1, with 23% at Index 2, and 38% at Index 3 or above (Figure 4). Double lactate extraction of P and K showed that 86% of soils were deficient in available P and 36% were deficient in available K. However, these data represent a mixture of land uses, including grassland, and may be biased, since farmers are more likely to send soils for analysis when a deficiency is suspected.

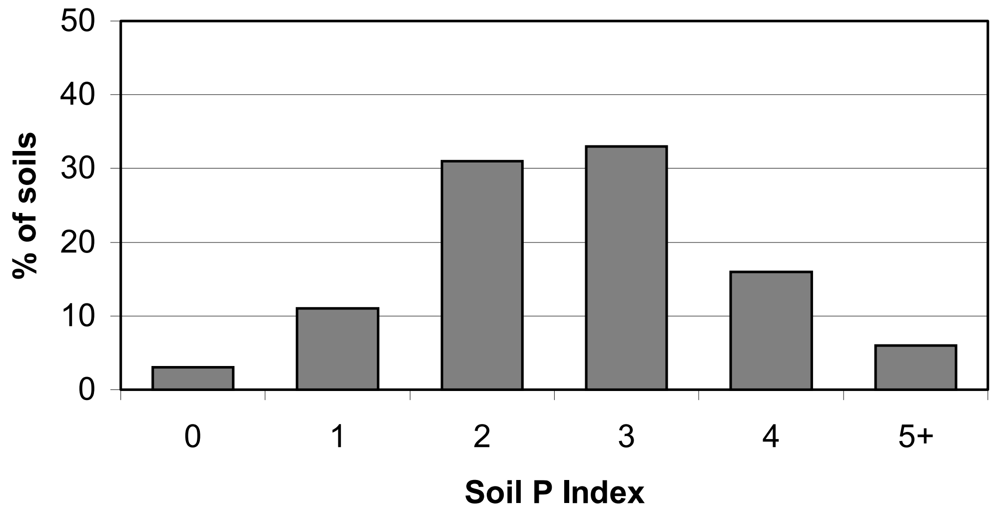

Figure 2 P status of arable soils in England and Wales (MAFF, 1989-91).

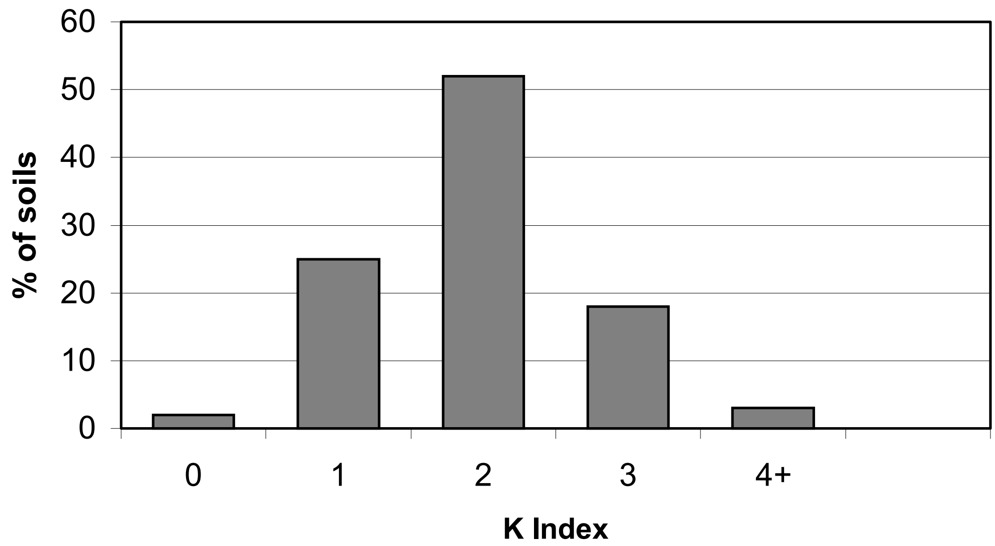

Figure 3 K status of arable soils in England and Wales (MAFF, 1989-91).

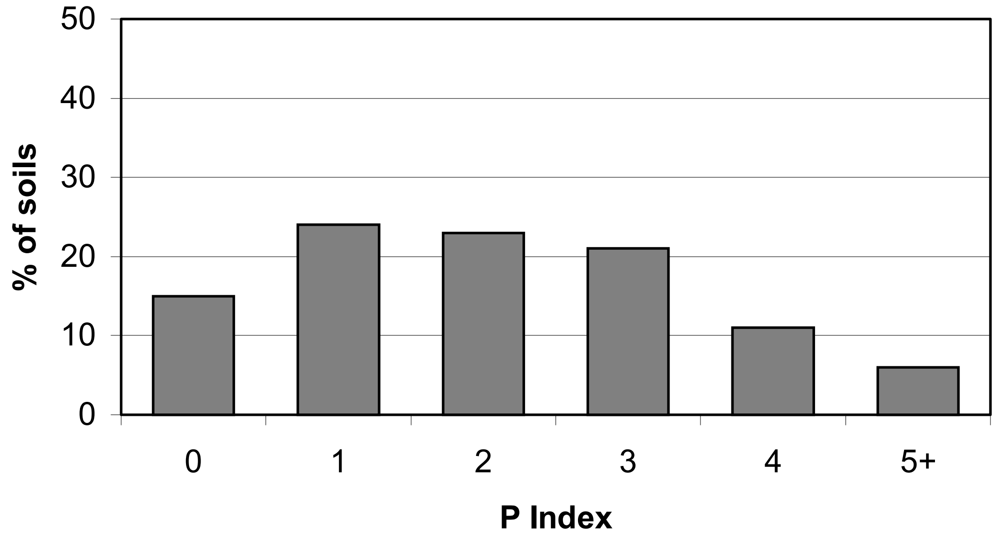

Figure 4 P status of soils from organic farms (EFRC records, 1997-1998).

Tables 3 and 4 show P and K budgets for three organic farms, where purchased feed represents a major input of P and K, while grain, milk and meat are the main outputs. The nutrient budgets (Farm 2 and Farm 3; Tables 3 and 4) show that organic systems can be very well balanced, this is in contrast to many conventional systems, which display large P surpluses, (Tunney *et al.*, 1990; Sharpley *et al.*, 1994; Haygarth *et al.*, 1998). However, the budgets also indicate that farms can vary due to different management practices. At Farm 1, the import of poultry manure had a significant impact on the P and K nutrient budgets. Although the import of poultry manure to Farm 1 has now ceased and organic standards now limit the use of manure produced off farm, it demonstrates that organic farms may also show a surplus that could, in some cases, lead to an accumulation of soil nutrients. This is likely to be the case where manure is spread on to land, which already has a high P or K status. Where there is a large surplus (Farm 1), environmental issues need to be considered, while in the case of farms showing a net loss of nutrients, changes may need to be made in order to sustain the farming system. Within the farm itself there may also be large differences in nutrient status over time, with soil nutrient status rising in areas which receive manure, etc., more frequently and declining on fields that receive less inputs or have larger nutrient offtakes. For nutrient budgets to be of use in predicting long term trends, e.g. in soil nutrient status, several years of data need to be considered. This is especially the case in organic systems where management is on a rotational or long-term basis. Also, the applications of slow release fertilisers, such as rock phosphate, may cause an erroneous picture to be drawn if budgets are drawn up just for the year of application. Studies by Nolte & Werner (1994) and Kaffka & Koepf (1989) have demonstrated negative balances for biodynamic farms. However, Kaffka & Koepf (1989) believed the system could remain sustainable for some time due to the release of P and K from soil reserves. There are also suggestions that organic farms may maintain lower soil nutrient levels as an adaptation to lower inputs (Loes & Ogaard, 1997). It may not be sensible therefore to compare organic farms directly with conventional farms. The less intensive nature of production under organic standards may also mean that lower soil P and K levels are acceptable.

Table 3 Farm gate P budgets for three mixed organic farms with dairy herds in the UK: Farm 1 is accumulating P (P index of 3-4) due to import of poultry manure. Farm 2 shows a small P surplus and Farm 3 a small P deficit, with a P index of 0-1.

INPUTS	Farm 1	Farm 2	Farm 3	OUTPUTS	Farm 1	Farm 2	Farm 3
		(kg P ha^{-1})				(kg P ha^{-1})	
Stock	0.4		0.15	Stock sales	1.3	0.6	1.61
Bought-in feed	9.0	9.60	3.67	Stock death			0.33
Rain		0.03	0.10	Animal			
Seed	0.2		0.58	(milk, wool)	3.9	5.4	2.77
Straw	1.1	0.30		Grain	4.2		4.10
Poultry manure	20.5			Vegetables	0.3		
Total	31.2	9.93	4.5		9.8	6.0	8.8
Balance					+21.4	+3.9	-4.3

Farm 1 (Fowler *et al.,* 1993), Farm 2 (Cuttle and Bowling, 1997), Farm 3 (unpublished data).

Table 4 Farm gate K budgets for three mixed organic farms with dairy herds in the UK: Farm 1 has a large surplus of K due to import of poultry manure. Farm 2 shows a small K surplus and Farm 3 a small K deficit.

INPUTS	Farm 1	Farm 2	Farm 3	OUTPUTS	Farm 1	Farm 2	Farm 3
		(kg K ha^{-1})				(kg K ha^{-1})	
Stock purchases	0.1	0	0.04	Stock sales	0.4	0.1	0.64
Bought-in feed	20.2	18	2.40	Stock death	0	0	0.03
Rain	0	3	2.50	Animal			
Seed	0.4	0	0.40	(milk, wool)	5	8.4	2.60
Straw	5.3	4	0	Grain	5.2	0	6.86
Poultry manure	39.5	0	0	Vegetables	1.8	0	
Total	65.5	25	5.3		12.4	8.5	10.1
Balance					+53.1	+16.5	-4.8

Farm 1 (Fowler *et al.,* 1993), Farm 2 (Cuttle and Bowling, 1997), Farm 3 (unpublished data).

There is clearly a gap in our knowledge on the effects of organic farming on soil nutrient status in the long term. A combined approach of soil analysis and budgeting will allow improved rotation design and planning for organic systems, optimising P and K use by crops while minimising adverse environmental impact.

Acknowledgements

This work is funded by the UK Ministry of Agriculture Fisheries and Food. IACR-Rothamsted also acknowledges the grant-aided support of the Biotechnology and Biological Sciences Research Council.

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Analysing non-replicated data from cropping systems experiments

G. Mikkelsen
Department of Crop Physiology and Soil Science, P.O. Box 50, 8830 Tjele, Denmark

Summary

Research in cropping systems in Denmark was started at three sites in 1985. Crop rotations were defined and implemented for ecological and integrated farming strategies. This paper focuses on production and nutrient indicators for a rotation for organic dairy farming. Sustainability is one of the key goals for all organic productions. One aspect of sustainability is the build-up and maintenance of soil fertility and nutrient levels.

High yields is a requirement also in organic farming. The uptake of nutrients is a very effective way of preventing loss of nutrients. The nutrient balances show that for all years the export of nitrogen and potassium harvested exceeds the input from fertiliser. For phosphorus there is nearly a balance. Soil analyses indicate that plant available phosphorus decreases slightly from year to year and the level is fairly near the level critical for production. The picture for potassium is not so clear but the level in the soil is low.

Introduction

Research in cropping systems is a discipline undertaken by nearly all European countries. The layout, crop rotations and design are described in Vereijken (1994, 1995, 1996, 1998). Common for this research methodology is that all fields are big, at least one hectare and all crops in a rotation are represented each year. Each crop rotation is kept under specified regulations as with real production systems, e.g. organic dairy production. The experimental areas are placed at state research stations. In connection with the experiments a network of pilot farms has been established. The development of the systems are evaluated according to a number of parameters and methods described by Vereijken (1992).

The aim of the research on cropping systems is not to compare the different systems but to evolve individual systems of sustainable resource utilisation. There is a close connection between designing, testing and improving the systems. A key element has been crop protection in organic farming or in low pesticide input systems (Wijnands, 1990) and methods have been developed to reduce pesticide use and the impact of pesticides on the environment (Wijnands, 1997). The protection of the environment and the coexistence of the natural flora and fauna with a professional agricultural activity are essential elements in many of the research activities. An example is the British LIFE project described by Jordan & Hutcheon (1995). Resource use and management in different systems are also topical in many countries. Helander (1997) described different strategies for energy production and how ecological principles and management can be managed with minimal resources.

Research in cropping systems in Denmark was started in 1985 at three state research stations with an initial characterisation of the experimental sites (Heidmann, 1989a,b,c,d). Thereafter organic and integrated farming strategies were defined for different rotations (Mikkelsen & Mikkelsen, 1989).

This paper focuses on evaluating the sustainability in a rotation for organic dairy production. Sustainability is one of the key goals for all organic productions. One aspect of sustainability is the build-up and maintenance of soil fertility and nutrient levels over the long-term. The experiments are not replicated and must be analysed differently from traditional factorial experiments.

Materials and methods

The ecological crop rotation for dairy farming was started in 1987 at Research Centre Foulum, which is situated in the centre of Jutland. The soil type is a sandy loam. All crops are represented each year and the fields are about one hectare in size. The rotation consists of the following crops:

1. Spring barley with under-sown grass-clover
2. 1st year grass-clover
3. 2nd year grass-clover
4. Barley/pea with undersown ryegrass
5. Oat/winter wheat (from 1994)
6. Fodder beet.

The fertilisation is by cattle slurry at a rate corresponding to one livestock unit per hectare, which is an average of about 100 kg ha^{-1} of total nitrogen. The slurry is analysed for content of total nitrogen, mineral nitrogen, phosphorus and potassium. A sample is taken for each field and analysed. Sowing, soil tillage and mechanical weed control are performed by standard farm equipment. For cereals, varieties and variety mixtures are chosen from year to year. The grass-clover fields are sown with a standard mixture of grass and clover, clover always being white clover. The fields are not grazed and the slurry is delivered from a nearby farm. The crops are not irrigated.

All fields are divided into two areas. A research area where the project activities are situated and a so-called reference area free from research activities. Here a monitoring program is maintained describing the consequences of the farming strategy on a number of parameters. The monitoring is carried out from two well-defined points and Heidmann (1989a) described the sampling strategy.

Yield is measured in all crops and every year in four replicates of 15 m^2 at fixed positions in all fields. The uptake of nitrogen, phosphorus and potassium is measured in all crops. The measurement in grass-clover is carried out for every cut. The number of cuts vary between years depending on the climatic conditions.

Soil nutrient contents are measured in soil samples taken in every field each year. Soil samples are taken at the same two reference points as the yield measurements. The contents of plant available phosphorus and potassium are measured.

Simple nutrient balances were calculated based on the input from fertiliser and output in the harvested crop. Nitrogen fixation from grass-clover and the barley/pea crops is not included in the balance.

Results and discussion

High yields are beneficial both for the ecological farmers and for the environment. The uptake of nutrients is an efficient way of preventing their loss. For ecological productions with nearly half of the area covered with nitrogen-fixing crops there is a high input of nitrogen to the soil, especially when a second-year grass-clover is mulched into the soil. In addition to nitrogen-fixing crops, there must be crops able to take up the soil mineral nitrogen. Management strategies must focus on conserving nitrogen within the soil-crop environment. Table 1 shows the yield for the organic fodder crop rotation.

Table 1 Crop yield in t DM ha^{-1} for the organic fodder crop rotation. Cereal yields are shown with a water content of 15%.

Crop	1990	1991	1992	1993	1994	1995	1996	1997
Barley gr.-cl	5.7	4.2	2.6	3.3	4.4	4.3	5.4	5.6
1st grass-clover	7.9	10.9	10.1	10.0	6.8	8.1	4.5	9.7
2nd grass-clover	8.1	8.9	10.8	10.6	7.6	9.8	5.6	10.6
Barley/pea gr.	9.4	7.6	5.8	5.2	7.4	6.8	7.5	8.4
Oat/wheat	4.8	5.7	4.3	3.2	7.8*	5.6*	6.2*	6.6*
Fodder beet	16.7	18.1	12.7	16.2	10.3	10.9	15.0	19.8

*: Winter wheat

Fodder crops such as grass-clover and fodder beets are very productive crops, which are efficient in taking up soil nutrients and covering the soil during a long growing season. The yield variation from year to year depends on climatic conditions and is greater for cereals than for fodder crops due to the longer growing season and because the crops are not irrigated.

The uptake of nitrogen for this rotation is a key element in preventing nitrate leaching. Table 2 shows the simple nitrogen balance for total nitrogen. Input is from slurry and output is the nitrogen content in the harvested crop, including nitrogen fixation.

Table 2 Simple nitrogen balance for total-N in kg N ha^{-1}. Added nitrogen minus harvested nitrogen.

Crop	1990	1991	1992	1993	1994	1995	1996	1997
Barley gr.-cl.	84	-68	46	14	16	42	30	-68
1st grass-clover	-109	-240	-240	-209	123	-156	-32	-158
2nd grass-clover	-51	-127	-186	-233	-141	-70	-23	-167
Barley/pea gr.	-33	-102	-65	-44	-92	-85	-95	-111
Oat/wheat	41	-30	54	14	89*	90*	57*	72*
Fodder beet	50	21	29	-1	22	62	-3	5
Total	-3	-91	-60	-76	-38	-20	-11	-71

*: Winter wheat

Every year more nitrogen is harvested than the input from fertiliser because nitrogen fixation is included in the harvested crop. Nitrogen fixation delivers nitrogen to optimise the fodder yield and fodder quality but, in addition, grass-clover enriches the total system with nitrogen. If the nitrogen status is low when clover passes the field, the fixation will increase and enrichment of the system will increase and vice versa. Clover thus acts as a nitrogen buffer for the system.

For phosphorus and potassium it is quit a different story. Enrichment of the soil only takes place when more nutrients are added than the crop can utilise. The contents in slurry of N, P and K are not necessarily adjusted to the need of the crops. Tables 3 and 4 show the balances for P and K.

Table 3 Phosphorus balance in kg P ha^{-1}. Added phosphorus minus harvested phosphorus.

Crop	1990	1991	1992	1993	1994	1995	1996	1997
Barley gr.-cl.	18.9	0.5	19.5	8.3	-9.4	7.0	10.1	-10.3
1st grass-clover	3.8	-25.8	-19.5	-20.6	-10.0	-14.3	0.4	-15.7
2nd grass-clover	20.7	-1.0	-1.3	-11.2	-4.4	0.0	8.0	-6.7
Barley/pea gr.	1.0	-8.5	0.5	-1.6	-17.0	-15.9	-15.6	-20.3
Oat/wheat	8.5	-1.6	17.2	7.0	23.1*	16.6*	14.0*	-0.8*
Fodder beet	41.2	17.1	28.1	15.1	21.9	28.3	25.0	21.2
Total	15.7	-3.2	7.4	-0.5	0.7	3.6	7.0	-5.4

*: Winter wheat

Table 4 Potassium balance in kg K ha^{-1}. Added potassium minus harvested potassium.

Crop	1990	1991	1992	1993	1994	1995	1996	1997
Barley gr.-cl.	95	29	89	51	40	30	-15	-58
1st grass-clover	-104	-257	-234	-191	-91	-119	-19	-189
2nd grass-clover	-34	-90	-106	-128	-52	-54	43	-147
Barley/pea gr.	-30	-39	-17	-5	-78	-64	-52	-80
Oat/wheat	43	3	96	48	126*	96*	121*	-9*
Fodder beet	74	-67	27	-31	51	34	142	-100
Total	7	70	-24	-43	-1	-13	37	-97

*: Winter wheat

Table 3 shows that there is nearly balance between inputs and outputs of phosphorus. The soil will thus neither be enriched nor depleted from P. Under Danish conditions there will be no loss of phosphorus to the environment. The fields are flat and surface run-off is minimal. For potassium it is seen that more is harvested than is added with manure. In addition to this there will be leaching of potassium on this soil type. There is thus a relatively high depletion of the soil content of potassium.

Maintaining soil fertility in the long-term will depend on the ability to keep soil nutrients at the same status through a number of years. Different crops deplete soil nutrients to different levels. These calculations must therefore cover several years.

In this rotation the fertilisation level is one livestock unit per hectare but the production is able to feed up to 1.3 livestock units per hectare. The consequence of this is a net export of nutrients out of the system. Figure 1 shows the amount of plant available phosphorous in soil. The measurement is performed in each of the six fields in the rotation. There is in each field a clear downward trend and the available amount is slightly decreasing from year to year, showing both a crop and year specific response. Comparing the phosphorus balance in Table 3 and plant available phosphorus in soil, it is seen that phosphorus must be immobilised in the soil to a certain degree, because imports are larger than export. On this sandy soil the P-index is recommended to be between 3 to 6 to ensure optimal plant availability and to prevent loss to the environment. Figure 1 shows that the phosphorus level in soil is apparantly critically low.

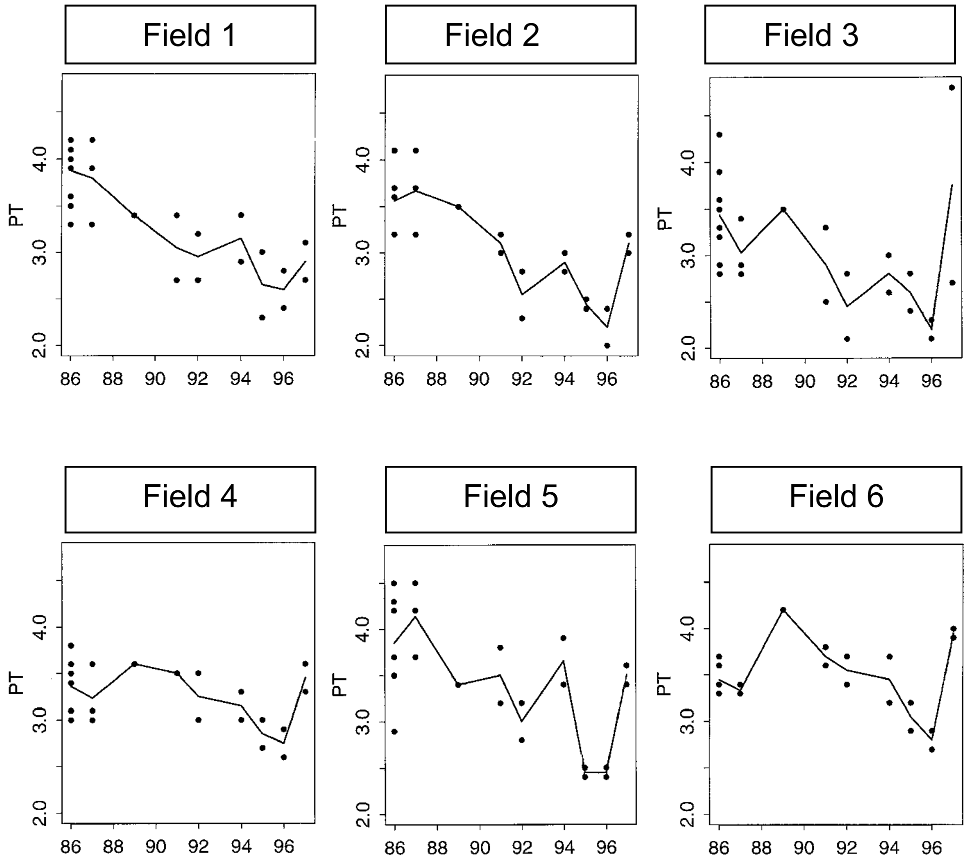

Figure 1 Index for plant available phosphorus in each of the six fields.

Fodder crops have a high requirement for potassium, especially grass-clover and whole-crop for silage. Grass-clover is only fertilised with the amount that grazing animals would have left in the field, but these fields are cut with the result that much more potassium is removed than re-circulated if they had been grazed. Figure 2 shows for each field the amount of plant-available potassium in the soil. The picture is not so clear as for phosphorus. The crop/year response is larger than for phosphorus, but the soil seems to release potassium because the balance in Table 4 is negative. In addition to the harvested potassium there will be leaching because of percolating water. The K-index of soil should, for sustainability, be between 7 and 11. The soil potassium level shown in Figure 2 must therefore be characterised as low to moderate.

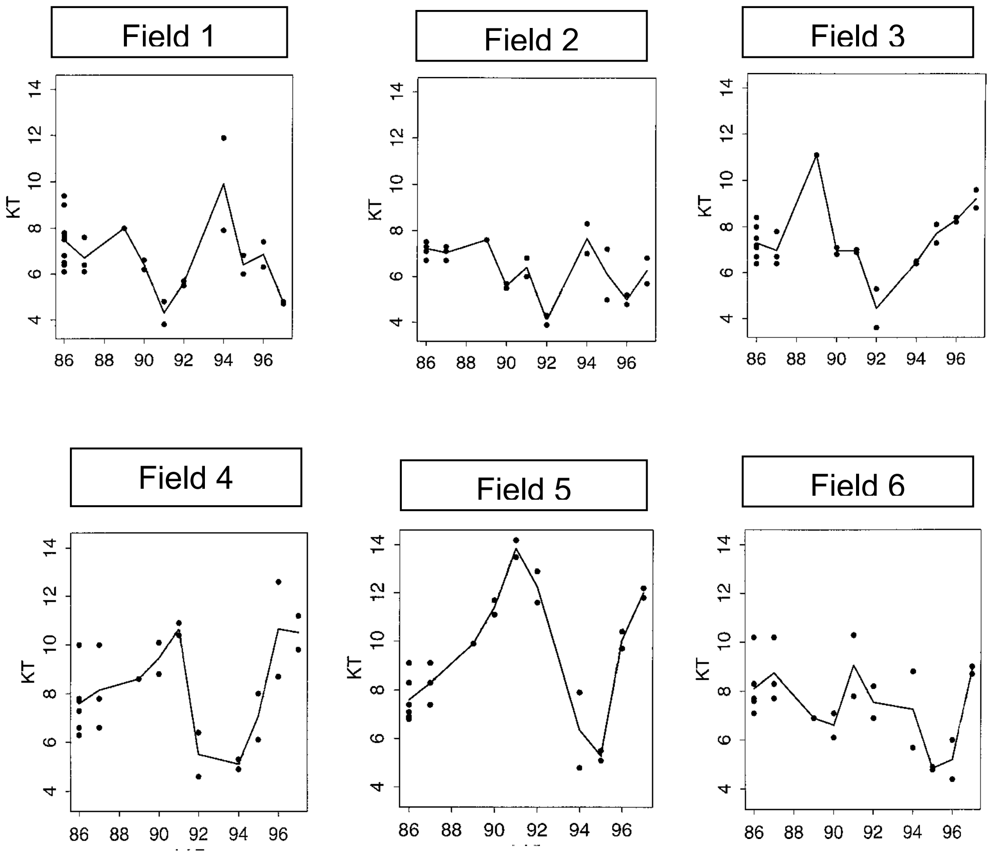

Figure 2 Index for plant available potassium in each of the six fields.

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Soil fertility

Yield of a grass-clover crop rotation and soil fertility in organic and conventional farming systems

P. Mäder, A. Fließbach, T. Alföldi and U. Niggli
Research Institute of Organic Agriculture, Ackerstrasse, CH-5070 Frick, Switzerland

Summary

Crop rotations including grass-clover have a long tradition in Switzerland not only in organic (biological) but also in conventional farming systems. In biological farming systems legumes play a key role as a nitrogen source for other crops and in the maintenance of soil fertility. In the framework of the DOC long-term comparison trial conducted at Therwil (near Basel), crop yield of roots, cereals and grass-clover of three consecutive seven year rotations were assessed under bio-dynamic, organic and under two conventional (with and without manure) farming systems. In this time span, nutrient input to the biological systems was around 50% lower than to the conventional system, with respect to nitrogen, phosphorus and potassium.

Averaged over all crops, yield in both biological systems was 20% lower than in the conventional systems, mainly as a result of the lower nutrient input, but also due to the different plant protection management. System effects on crop yield were most obvious with potatoes, caused by the high demand for nitrogen and potassium in a relatively short growing period. Winter wheat yields in the biological systems were about 10% lower than in the conventional systems. Differences in grass-clover yield were small during the first two crop rotation periods. In the third crop rotation period, however, grass-clover yield in the biological systems was distinctly lower than in the conventional systems. Even though yield for all crops was lower in the biological systems, energy use per unit crop yield was 20 to 30% lower than in the conventional system, except for potatoes.

Soil fertility was enhanced in the biological plots compared to the conventional plots as indicated by a higher microbial biomass and an enhanced mycorrhizal root colonisation. Moreover, the functional diversity of soil microorganisms and their efficiency to metabolise organic carbon sources was increased in the organically fertilised systems with highest values in the bio-dynamic soils. The results are encouraging regarding soil aggregate stability and microbial phosphorus delivery for crops, which were found to be higher in the biological systems.

Introduction

The interest in organic farming systems has increased during the last two decades since disadvantages of intensive agriculture practice became evident. Moreover, several countries are subsidising organic farming by direct payment to compensate for potentially lower yield and to increase the farmers role in environmental protection. These countries also show markedly increasing numbers of farms in conversion to organic farming (2% to 10% of the agricultural area are already organic; e.g. Germany 2%, Sweden 4%, Denmark 6%, Finland 6%, Switzerland 7%, Austria 10%) (SÖL, 1999; see also

Internet http://www.irs.aber.ac.uk/research/Organics/europe/). In addition, farmers who manage their farms according to the guidelines of organic farming achieve an enhanced income by higher prices for their products.

With respect to the increase of the agricultural land managed organically, the question raises: how sustainable is organic crop production? Conventional farmers use high amounts of synthetic mineral fertilisers to amend their crops. In organic farming, the use of synthetic mineral fertilisers such as ammonia nitrate are not allowed (EU Directive 2092/91). As a consequence, crop rotations including nitrogen fixing legumes play a key role in organic farming. Moreover, easily soluble phosphorus fertilisers (e.g. super phosphate) are forbidden. Plant nutrients are expected also to become available by weathering, by mineralisation of organic matter, and by mineralisation of nutrients contained in organic fertilisers and plant litter. In Switzerland, traditionally, crop rotations include grass-clover mixtures, which are fed to the livestock on mixed farms, which are still widespread. Crops in the rotation are fertilised with farmyard manure (FYM) in organic farming and with FYM and mineral fertilisers or exclusively mineral fertilisers in conventional farming. We investigated the sustainability of grass-clover crop rotations in a long-term comparison trial in organic and conventional farming systems. The aim of the study was to assess the long-term crop productivity and the influence of the farming systems on soil fertility.

Material and methods

The field experiment was set up in 1978 in the vicinity of Basel (at Therwil, Switzerland; 7°33'E, 47°30'N) by the Swiss Federal Research Station for Agroecology and Agriculture, Zürich-Reckenholz (CH), in cooperation with the Research Institute of Organic Agriculture, Frick (CH). The four farming systems differed mainly with respect to fertilisation strategy and the concept of plant protection management (Table 1).

Table 1 Main differences between the farming systems

Treatment	Unfertilised NOFERT	Bio-dynamic BIODYN	Organic BIOORG	Conventional with manure CONFYM	Convention no manure CONMIN[1]
Fertilisers	none	farmyard manure (FYM) 1.2-1.4 LU ha yr^{-1}		FYM + mineral fertiliser	mineral fertiliser
		composted manure	rotted manure	stacked manure	
Weed control	mechanical			mechanical+herbicides	
Diseases	indirect methods, rock dust, copper			chemical (thresholds)	
Insects	plant extracts, bio-control			chemical (thresholds)	
Special	biodynamic preparations		none	growth regulation (CCC)	

1) The CONMIN plots remained unfertilised during the 1st crop rotation (1978-1984). According to Besson and Niggli (1991).

The biological systems bio-dynamic (BIODYN) and organic (BIOORG) were fertilised with farmyard manure (FYM) and slurry corresponding to 1.2 to 1.4 livestock units per hectare. (Note: In this paper, the term 'biological' farming, synonymous for 'organic' farming, is used as defined in the EU Directive 2092/91, released by the European Community in 1991). One conventional system was fertilised with the same amount of FYM as the biological systems and, in addition, with mineral fertilisers up to the recommended level of the plant-specific Swiss standard recommendation (system CONFYM). The other conventional system was unfertilised during the first crop rotation, but was then amended with mineral fertilisers exclusively (system CONMIN). The conventional systems were farmed according to the national rules of integrated plant production. Table 2 shows the nutrient input for the four farming systems in the three crop rotations. Control plots did not receive either fertilisers or pesticides (NOFERT).

Table 2 Input of nutrients *via* farmyard manure and mineral fertilisers to the farming systems in three consecutive crop rotations of the DOC long-term trial (values in kg N, P, K ha^{-1} yr^{-1}).

		Farming systems [1)]				
Nutrients	**Rotation**	**NOFERT**	**BIODYN**	**BIOORG**	**CONFYM**	**CONMIN**
N_{total}	1	0	109	106	131	0
	2	0	100	93	144	105
	3	0	89	79	172	145
$N_{mineral}$ [2)]	1	0	46	39	83	0
	2	0	26	31	89	105
	3	0	30	24	116	145
Phosphorus	1	0	27	32	49	0
	2	0	30	27	44	46
	3	0	16	24	35	37
Potassium	1	0	128	125	264	0
	2	0	112	123	247	226
	3	0	234	146	293	280

[1)] For farming systems see Table 1. [2)] $N_{mineral}$ = NH_4-N + NO_3-N. Adapted from Dubois *et al.* (1999).

Plant protection was conducted according to the guidelines of the bio-dynamic and organic systems (Table 1). In the conventional systems, pesticides were only applied if economic thresholds were exceeded according to the integrated scheme of plant protection. Plant protection in the unfertilised control was the same as in the bio-dynamic system.

The crop rotation was identical in all systems, namely: potatoes followed by rape as green manure, winter wheat followed by vetch/rye fodder intercropping, cabbage or beetroots, winter wheat, winter barley and two years of grass-clover meadow. In the third crop rotation, barley was replaced by a third year of grass-clover. The grass-clover mixture was sown in drills after rotary harrowing the cereal stubble field. Soil tillage was similar in all treatments. The soils were ploughed to a depth of 18 to 20 cm before planting potatoes, winter wheat, cabbage or beetroots.

The soil type is a luvisol (sandy loam) on deep deposits of alluvial Loess. It contains 15 % sand, 70 % silt and 15 % clay. The field trial was designed as a randomised block with four replicates including three crops planted simultaneously in each treatment every year. Single plot size was 5 m × 20 m. The climate at the experimental site is rather dry and mild with a mean precipitation of 785 mm per year and an annual mean temperature of 9.5°C.

Results and discussion

Crop yield

The crop yield of the two biological systems was markedly lower than of the two conventional systems, which is mainly attributable to differences in fertilisation and plant protection. Average reduction over all crops figured about 20% (Table 3).

Potato yield in the biological systems was around 40% lower than in the conventional plots. Leaf senescence of biologically cultivated potatoes started earlier than in the conventional system, mainly due to a low potassium supply in the biological plots (Berchtold *et al.*, 1993). Moreover, in the biological treatments a severe incidence of leaf pathogens such as *Phytophtora* and *Alternaria* was recorded in some years, drastically reducing the photosynthetically active leaf surface. In contrast, these pathogens could be controlled efficiently by organic and inorganic fungicides in the conventional systems.

Table 3 Yield of potatoes, winter wheat and grass-clover in three consecutive crop rotations of the DOC long-term trial.

		Farming systems [1)]				
Crop	**Rotation**	**NOFERT**	**BIODYN**	**BIOORG**	**CONFYM**	**CONMIN**
Potatoes	1	21.7	34.9	39.5	57.1	24.1
t FM[2)] ha^{-1}	2	9.1	27.7	33.2	50.0	49.3
n = 3	3	9.8	31.3	31.5	50.7	49.6
Winter wheat	1	3.4	3.5	3.6	3.7	3.6
t DM[3)] ha^{-1}	2	2.7	3.8	4.1	5.0	5.2
n = 6	3	3.0	4.1	4.1	4.6	4.8
Grass-clover[4)]	1	115	134	131	145	114
t DM ha^{-1}	2	99	130	133	149	134
n = 3	3	71	122	110	147	128

[1)] For farming systems see Table 1. [2)] Fresh matter. [3)] Dry matter. [4)] Mean of 1st and 2nd yr.

During the first crop rotation, yields of winter wheat did not differ between the farming systems. However, there were considerable differences in the second rotation period with a new variety, concomitant with the application of fungicides, insecticides and plant growth regulators in the conventionally farmed plots. In the third rotation, grain yield of both biological systems was around 10% lower as compared to the conventional systems.

The comparatively small differences between farming systems in grass-clover yield in the first two crop rotations (around 10%) may be caused by a higher clover content with its N-fixing *Rhizobium* symbiosis and a higher root colonisation by mycorrhizal fungi in the biological treatments (see below), leading to a more efficient nutrient supply. However, grass-clover yield decreased during the third crop rotation in the biological systems. The reason for this may be a change of the grass-clover mixture, or the later sowing date after winter wheat in the third rotation as compared to the earlier sowing date after barley in the first and second rotation.

Generally it seems that the yield reduction in biologically cultivated crops is higher in crops with a relatively short vegetation period, such as potatoes, than for crops with a longer vegetation period, such as cereals and clover grass. These crops generally build up a high root biomass, allowing for a more efficient exploitation of soil nutrients. Even though yield for all crops were lower in the biological systems, energy use per unit crop yield was 20 to 30 % lower than in the conventional system, except for potatoes (Niggli *et al.*, 1995).

Soil fertility

Soil fertility in the DOC trial was assessed by chemical, biological, and physical methods. As a result of the lower input of phosphorus and potassium in the biological systems, soluble fractions of these elements were lower than those in the conventional systems, whereas calcium and magnesium were higher (Alföldi *et al.*, 1993). Moreover, the flux of phosphorus between the matrix and the soil solution was highest in the bio-dynamic system (Oberson *et al.*, 1993).

Soil microorganisms are a fundamentally important component of terrestrial habitats, playing key roles in ecosystem function. Their primary role consists in governing the numerous nutrient cycling reactions which are essential in the maintenance of soil fertility and plant nutrition. Soil microbial biomass is a sink and a source of nutrients. On biomass build-up nutrients will be immobilised, on death released. Microorganisms are also involved in the genesis and maintenance of soil structure. Most parameters that can be assessed to measure microbial pool sizes and microbial activity (basal respiration, enzyme activities) showed the same ranking among the treatments of the trial: NOFERT = CONMIN < CONFYM < BIOORG < BIODYN (Mäder *et al.*, 1996). Oberson *et al.* (1996) have shown, that the microbial contribution to the plant's phosphorus supply increases in the same rankage. Ongoing work showed a phosphorus flux through the microbial biomass being four times (BIODYN) and two times (BIOORG) higher than in the minerally fertilised conventional system (F. Oehl, unpublished).

As an example, soil microbial biomass in the plough layer (0 to 20 cm), estimated at the end of the third crop rotation by the fumigation extraction method, is shown in Figure 1. Differences between farming systems were highest in winter wheat plots and lower in plots cultivated three years with grass-clover. We expected that the cultivation of grass-clover would diminish the effects of farming systems as a consequence of the intensive rooting and the root exudates. Moreover, no potentially harmful pesticides were applied in the conventional systems to this crop. However, the microbial biomass in the bio-dynamically cultivated plots was still enhanced, indicating profound changes in soil characteristics due to the farming systems. Also in the horizon 20 to 40 cm the same rankage of the farming systems was found, with highest values in the bio-dynamic system and lowest in the minerally fertilised conventional system. Pfiffner & Mäder (1998) found a significantly higher biomass and abundance of anecic, vertically burrowing earthworms in the biological plots of the DOC trial. This may have affected microbial properties in the soil layer below the plough horizon, because earthworm casts are known to be biologically very active.

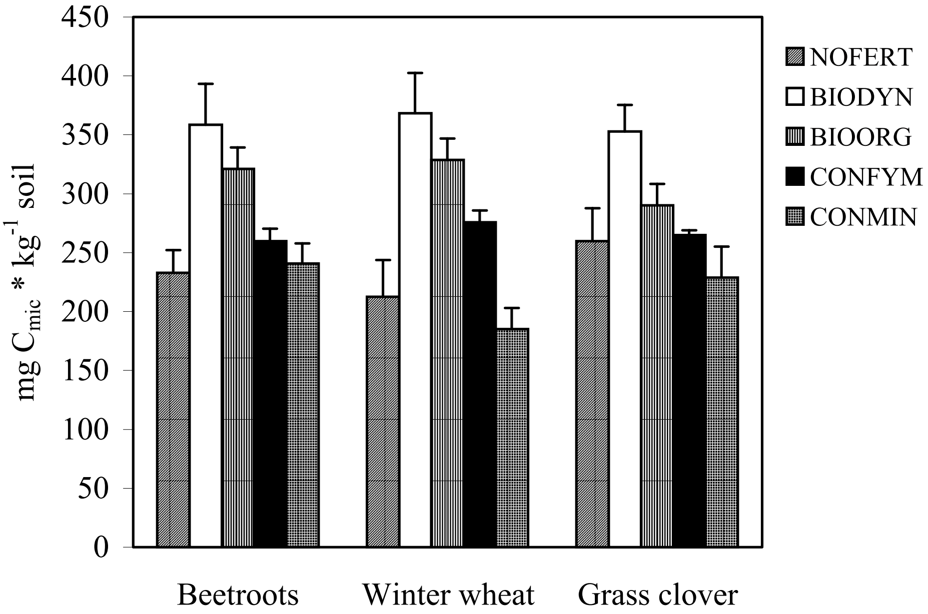

Figure 1 Soil microbial biomass under three crops after practising four farming systems for three crop rotations. NOFERT = unfertilised control, BIODYN = bio-dynamic, BIOORG = organic, CONFYM = conventional with manure, CONMIN = conventional without manure (exclusively minerally fertilised). Error bars = standard error of means. n = 4.

Carbon dioxide evolution from soil is a biological process mainly governed by microorganisms. Under carbon limiting conditions, which is normally the case in a soil, CO_2 evolution (basal respiration) per unit microbial biomass (qCO_2) indicates the energy used for microbial maintenance (Anderson & Domsch, 1990). A steady increase of this metabolic quotient (qCO_2) was stated in the order: BIODYN < BIOORG < CONMAN < CONMIN. The lower metabolic quotient in the organically fertilised systems, especially in the bio-dynamic system, indicates that these populations can utilise organic substances more efficiently than populations from minerally fertilised soils. Evidently, organic fertilisation favours soil microorganisms more than exclusive mineral fertilisation. Differences in the metabolic quotient further implies that a population shift between systems may have occurred. This hypothesis was tested applying the Biolog® system (BIOLOG Inc., Hayward, Cal.), where the substrate utilisation patterns of microbial populations were determined. In fact, functional diversity was highest in the bio-dynamic system and lowest in the minerally fertilised conventional system (Fließbach & Mäder, 1998). Moreover, microorganisms in bio-dynamic soil decomposed added ^{14}C-labelled plant material to a higher extent than in conventional soil. A higher proportion of the plant material was used for microbial biomass build-up.

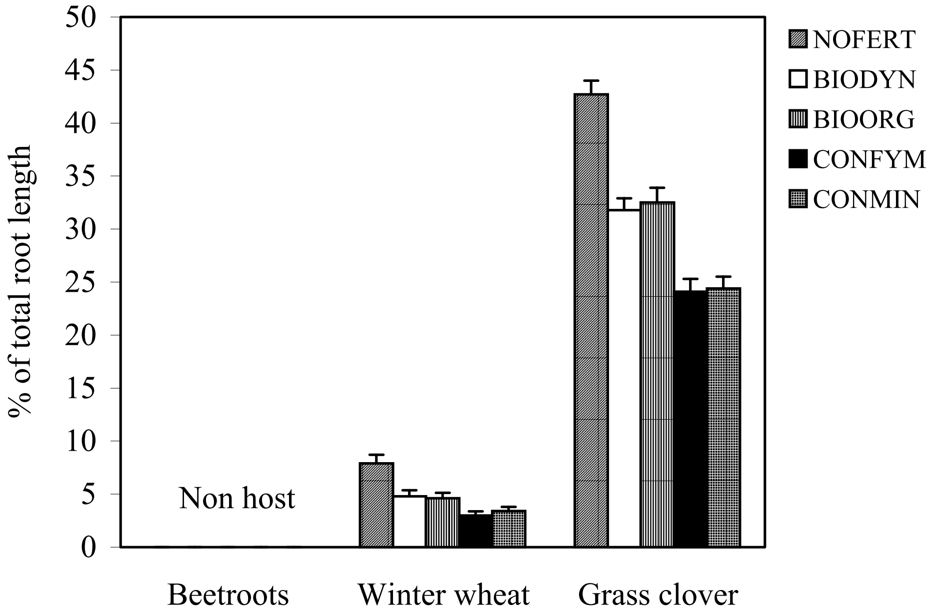

Figure 2 Mycorrhizal root colonisation of three crops after practising four farming systems for two crop rotations. NOFERT = unfertilised control, BIODYN = bio-dynamic, BIOORG = organic, CONFYM = conventional with manure, CONMIN = conventional without manure (exclusively minerally fertilised). Error bars = standard error of means. n = 4 for beetroots, 24 for winter wheat and 20 for grass-clover plots.

Most of the analysed soil microbial pool sizes and activities are indicators of soil fertility that are regarded as holistic parameters. Mycorrhizas as members of the soil population with specific functions play a key role at the plant–soil interface and are widespread in agricultural plants. Mycorrhizas are believed to ameliorate plant mineral nutrition, to enhance water stress tolerance and to contribute to a better soil aggregate formation, which is important for soil structure and stability against erosion (Smith & Read, 1997). These are key factors for successful low-input farming. Hence, the formation and functioning of the mycorrhizal symbiosis is expected to play an important role in sustainable agriculture. The role of the mycorrhizal symbiosis may be of particular importance for agroecosystems in which synthetic mineral fertilisers are replaced by organic ones, used at a low dosage as in biological farming. In these types of low-input systems, plants may benefit particularly from the mycorrhizal relationship by an increased uptake capability of the mineralised soil nutrients present only at low concentrations. The degree of root colonisation by mycorrhizal fungi was determined in field samples two to three times over the growing season in three of the crops included in the rotation, namely in beetroots, winter wheat and grass-clover. On average, we found the percentage of root length colonised by mycorrhizas to be around 40% higher in the plants grown in soils from the biological farming systems than in those grown in conventionally farmed soils, but root colonisation was strongly dependent on crops (Figure 2). Around 50 % of the variation of mycorrhizal root colonisation was explained by chemical properties of the soils (pH, soluble phosphorus and potassium, exchangeable magnesium), the effect of soluble soil phosphorus being most pronounced. In contrast to the microbial biomass and activity, the mycorrhizal root colonisation was highest in the unfertilised control plots. This may be explained by the fact that most soil microorganisms are carbon heterotrophic and thus dependent on decomposable carbon sources derived from plant litter, root exudates, manure and soil organic matter. Mycorrhizas, however, are directly linked to plant assimilates *via* the roots, which they allocate in the hyphosphere with its implications for soil aggregate formation. In fact, soils from biological plots had a higher aggregate stability as assessed by the percolation method (Siegrist *et al.*, 1998).

We can conclude that the crop rotation conducted in the DOC trial including root crops, cereals and legumes, was highly productive also in organic systems with its negligible external input in form of mineral fertilisers and pesticides over more than two decades. Moreover, it is remarkable, that even with an identical crop rotation and soil tillage scheme, soil fertility was enhanced in the biological systems. Organically manured legume based crop rotations are thus a true sustainable form of agricultural practice for many temperate regions in Europe.

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Effect of ecological and integrated arable farming systems on crop productivity and soil fertility

M. Lacko-Bartošová[1], A. Zaujec[2] and T. Števlíková[3]
[1]*Department of Agricultural Systems, SPU, 949 76 Nitra, Slovakia*
[2]*Department of Soil Science, SPU, 949 76 Nitra, Slovakia*
[3]*Department of Microbiology, SPU, 949 76 Nitra, Slovakia*

Summary

Integrated and ecological arable farming systems were established on brown clay-loamy soil in the south Slovakia in 1990. The chemical inputs in the integrated system were replaced in the ecological system by a multifunctional crop rotation, ecological plant nutrition, and mechanical and physical weed control. A simple model for carbon balance in agro-ecosystems was proposed. The results obtained by the model were satisfactory compared to field data. Ecological farming system showed slightly better physical and chemical soil parameters and higher quality of soil organic matter. The highest values of C_{ox}, N_{biol}, daily soil respiration and nitrification were measured in the ecological system. Differences of crop yields between the systems were greater under minimum cultivation than under conventional tillage. Compared to the integrated system, the ecological system reflected the rotational effect on the winter wheat yield more clearly. The precrop effect of leguminous crops on yield was higher for winter wheat in the ecological system.

Introduction

Integrated and ecological farming systems represent in the Slovak Republic non traditional ways of agroecosystem management. They are regarded as production methods, which enhance the quality of production and are compatible with increasing demands for environmental protection and landscape management. In 1998, ecological farming in the Slovak Republic represented 2.1% of agricultural land (50,600 ha). The project supported by the Scientific Agency of Ministry of Education SR, is aimed at the development of prototypes of integrated and ecological arable farming systems for the south Slovakia region.

Materials and methods

Integrated and ecological arable systems were established in the fall of 1990 near Nitra (18º07´E, 48º19´N) on an Orthic Luvisol developed at proluvial sediments mixed with loess. The altitude of the experimental plots is 178 m, and average monthly temperatures range from -1.7 to 19.7ºC. The A_1 soil horizon (0-0.32 m) has a fine to medium crumb structure, firm consistence, loamy texture, without lime, with a clear boundary to B_t (0.33-0.65 m), which has a subangular blocky structure, firm consistence, clay-loamy texture and gradual boundary to B_t/C (0.66-0.85 m). In both systems natural regulation processes are supported by crop rotations with intercrops (green soil cover), integrated crop nutrition and fertilisation, regulated and non-chemical plant protection. In both systems two different basic soil cultivation are used: conventional with ploughing to the depth of 0.24 m and minimum tillage with shallow cultivation to a depth of 0.12-0.15 m. Farm yard manure is incorporated with medium depth ploughing two times during rotation in the amount of 40 t ha^{-1}. In the ecological system, regulations for ecological agriculture in the Slovak Republic are followed. The crop rotations are shown in Table 1.

Table 1 Crop rotations in ecological and integrated system.

Integrated system		Ecological system	
1.	Alfalfa	1.	Bean+alfalfa
2.	Maize	2.	Alfalfa
3.	Maize for silage	3.	Winter wheat (intercrop)
4.	Winter wheat	4.	Maize for silage
5.	Sugar beet	5.	Winter rape (intercrop)
6.	Spring barley (intercrop)	6.	Common pea (intercrop)
7.	Common pea	7.	Maize for silage
8.	Winter wheat	8.	Winter wheat

A split-plot design within a complete block design with three replicates is used. Farming system with crop sequence served as the main plot, with factorial combination of tillage representing sub-plots. The size of the plots was 200 m^2. Soil samples were taken from fixed monitoring places. The data were evaluated statistically by analysis of variance. Determined soil productivity parameters were as follows:

- Content of organic carbon by Tyurin´s method in Nikitin´s modification
- Fractionation of humic substances by Tyurin´s method in Ponomareva-Plotnikova´s modification
- Chemical soil properties (soil pH, saturation of bases, CEC)
- Physical soil properties (bulk density, porosity, water and air capacity, soil structure-content of microaggregates, content of water stable aggregates)

Soil microbial parameters were

- Microbial biomass determined by the chloroform fumigation extraction method
- Soil respiration, carbon dioxide absorbed in KOH and determined by HCl titration
- Counts of soil microorganisms (bacteria, micromycetes, actinomycetes) estimated by the dilution method
- Inorganic nitrogen measured in fresh soil samples and after 14-days of aerobic incubation as N-NH4+ by colorimetric determination (with Nessler reagent) and N-NO3- by pheno-disulphonic acid
- Biologically released nitrogen (Nbiol) and nitrification calculated from measured values.

Results and discussion

Changes of soil organic carbon (SOC) reflect the result of carbon input to and losses from the soil. The amount of organic material (crop residues, organic fertilisers) obviously depends on the type of farming system established. Since the agricultural crops are regularly harvested and ploughed into the soil, there is no long-term carbon accumulation of crop biomass, and the changes in soil organic carbon record the net carbon balance of agro-ecosystems.

Soil organic carbon pools in the soils are generally large, relative to their annual changes. Our simple model, used in this study, simulates the carbon cycling in agro-ecosystems. Inputs of organic material to the soil after the harvest were calculated from crop yields according to the models of Jurcová & Bielek (1997). The fraction of the added organic material, still present after one year was calculated on the basis of a humification coefficient K_h. The values of K_h were determined from the C:N ratio and the chemical composition of fresh organic materials and ranged from 0.08 to 0.3. We assumed, that the humified soil organic matter would decompose at a constant rate. The mineralisation coefficient K_m was determined from soil texture and carbonate content and was 0.015 (Mazur *et al.*, 1993). SOC dynamics calculated by our simple model was compared to field data from two plots of both farming systems. Average values for each farming system are shown in Figures 1 and 2. Due to the spatial variations of total organic carbon, there were already differences between the systems at the beginning of the experiment. The obtained 9-year results showed some fluctuation during the experimental period. In both systems, the increase of SOC content between initial and final data was observed. The increase in SOC was higher in the ecological than the integrated system. In our study, the rate of C inputs was the most important factor determining the organic matter level in the soil. Annual organic-matter changes were roughly linear with respect to annual C-input rates. However, there were also significant differences in soil organic matter levels at approximately the same C-input rate. These differences were closely associated with the type of organic material added (C:N ratio, lignin content, etc).

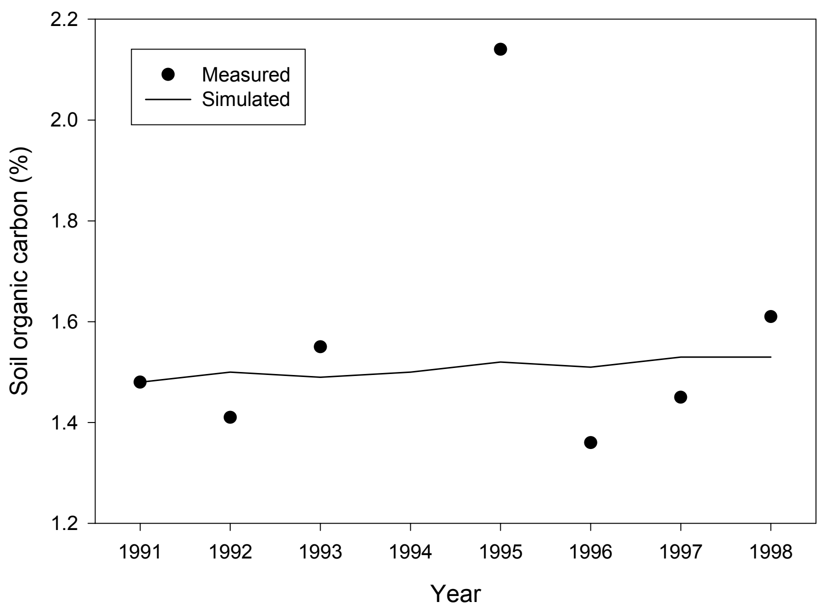

Figure 1 Development in measured and simulated soil organic carbon in the ecological farming system.

Table 2 Average values of selected soil chemical and physical parameters (1995-1998).

Parameter	Farming system Integrated	 Ecological
HA:FA	0.77	0.79
C_{tot} (%)	1.36	1.53
Base of saturation (%)	85	88
Porosity	38.1	38.9
Bulk density (kg m^{-3})	1607	1538
Macroaggregates >0.25 mm (%)	94.8	94.5
Water stable aggregates >0.25 mm (%)	46.1	48.4

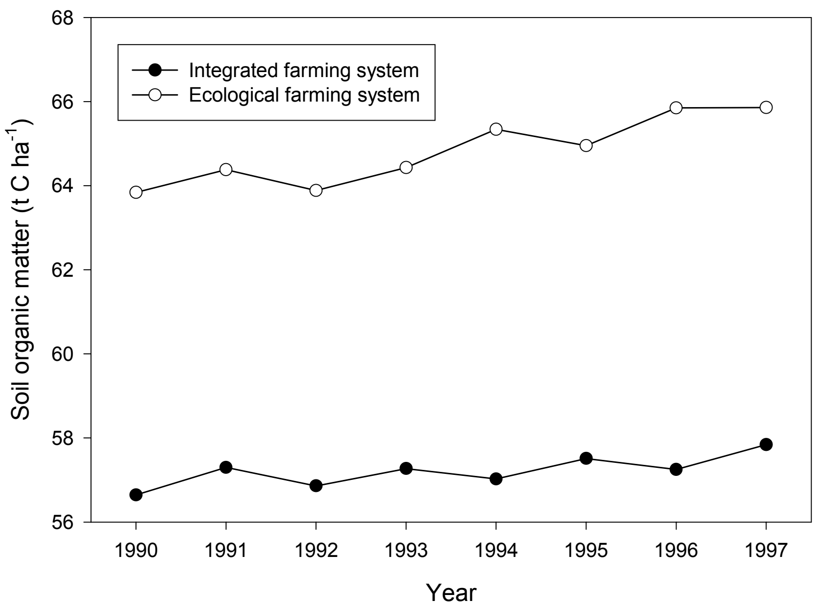

Figure 2 Development in the simulated soil organic matter in the integrated and ecological farming system.

Differences in physical and chemical soil properties, their spatial and temporal variations were determined. No significant correlation to crop rotations was found. There was a general tendency of improved soil parameters in ecological system compared with integrated (Table 2).

Post harvest residues and application of farm yard manure were the most important factors affecting the microbial processes in the evaluated farming systems. Within a measurement period of four years, there were no substantial differences in the average values of soil carbon content (C_{ox}), except of its temporal variation (Table 3). The values of total nitrogen (N_t) increased in all plots of integrated and ecological systems. The C:N ratio was therefore also changed. The mineralisation activity of soil microorganisms and the fertiliser application increased the amount of inorganic nitrogen present, mainly in IS. This increased the risk of nitrate leaching losses. Similar trends were observed in estimated amounts of biologically released nitrogen (N_{biol}) and intensity of nitrification. In the soil of the ecological system, the values of these indicators were higher, mainly in the plots where farmyard manure was used. Microbial biomass (C_{mic}) was measured only in 1997. In soil samples of ES, amount of biomass was higher at plots with FYM application. In 1997 the bacteria populations, which utilise organic and inorganic nitrogen pools, increased in comparison with 1993, but the amount of mycocenosa decreased to half. Actinomycetes responded to the change in pH by an increasing population.

Table 3 Soil microbial parameters in integrated and ecological farming systems.

		Farming system	
Parameter	**Year**	**Integrated**	**Ecological**
C_{ox} (%)	1993	1.25	1.28
	1997	1.20	1.29
N_t (%)	1993	0.143	0.183
	1997	0.178	0.230
C:N	1993	8.7	7.0
	1997	6.7	5.6
pH (K_{Cl})	1993	5.3	5.8
	1997	5.4	5.9
N_{in} (mg kg^{-1})	1993	6.7	7.1
	1997	15.4	13.1
N_{biol} (mg kg^{-1})	1993	7.1	6.8
	1997	8.6	17.1
Nitrification (mg kg^{-1})	1993	7.4	8.0
	1997	8.7	17.7
C in microbial biomass (mg kg^{-1} d.s.m)	1993	-	-
	1997	321	267
Mic. respiration (mg CO_2 $kg^{-1}.d^{-1}$)	1993	-	-
	1997	34.0	54.0
Bacteria on meat-peptone agar medium 10^6 g^{-1} d.w	1993	11.7	9.2
	1997	27.9	42.5
Bacteria on Thorton´s agar medium 10^6 g^{-1} d.w	1993	5.6	8.0
	1997	18.3	17.5
Micromycetes 10^3 g^{-1} d.w.	1993	213	251
	1997	125	106
Actinomycetes 10^3g^{-1} d.w	1993	-	-
	1997	197	428

The size of the microbial biomass and its activity is the characteristic of soil type and fluctuates within a dynamic equilibrium. Homeostasis mechanisms, however, works optimally only in a certain range of the environmental conditions and is affected by the soil and crop management systems (Vancura & Kunc, 1988). When these factors are changed, both the composition and the activity of microorganisms vary (Kopcanová *et al.*, 1994). According to our results, the microbial biomass cannot serve as an early indicator for farming system evaluation. Enzyme activities could be a more sensitive indicator of the soil management systems (Kandeler *et al.*, 1999). An unsolved problem in soil microbiology is the interpretation with regard to temporal, site specific as well as management factors. There are no minimum or threshold levels of microbial biomass or enzyme activity for certain soil type, cropping and farming systems.

Table 4 Average yields of crops in integrated (IS) and ecological systems after conventional soil cultivation in t ha^{-1} (1994-1998).

	Farming system		
	Integrated	Ecological	
Crop	**t ha^{-1}**	**t ha^{-1}**	**% of integrated**
Alfalfa	11.6	11.4	99
Maize	5.5	5.2	95
Maize for silage	11.7	10.5	90
Common pea	3.8	3.9	103
W. wheat after legume	6.3	6.2	99
W. wheat after maize	6.7	6.1	92

Table 5 Average yields of crops in integrated (IS) and ecological systems (ES) after minimum soil cultivation in t ha^{-1} (1994-1998). The yield of ES is expressed as fraction of IS and of conventional tillage (CT).

	Integrated system		Ecological system		
Crop	**t ha^{-1}**	**% of CT**	**t ha^{-1}**	**% of IS**	**% of CT**
Alfalfa	10.7	92	10.8	101	95
Maize	4.9	88	4.5	92	86
Maize for silage	10.1	87	9.8	96	93
Common pea	3.8	101	3.7	97	95
W. wheat after legume	6.0	96	5.7	95	92
W. wheat after maize	6.6	99	5.3	80	87

The achieved yields of common crops in both systems are presented in Tables 4 and 5. The interactive effects of farming systems and soil management on yields of winter wheat grown after maize for silage is shown in Table 6. According to results of the analysis of variance, the integrated system gave significantly higher yields of winter wheat (6.2 t ha^{-1}) than did the ecological (5.6 t ha^{-1}). Similarly the yields were higher under conventional cultivation than under minimum tillage (0.3 t ha^{-1}). Due to statistically insignificant effects of the interaction between the system and cultivation, the integrated system gives higher winter wheat yields irrespective of the cultivation method. The conventional cultivation in both systems results in higher yields.

There was no statistical difference between the yields of winter wheat grown after leguminous crop within a recorded period of 5 years. The precrop effect of leguminous crops was more yield-promotive for winter wheat in ecological system. Compared to the integrated system, which included additional N fertilisation, the ecological system reflected the rotational effect on the w. wheat yield more clearly. There were no substantial differences between achieved yields of alfalfa, maize for grains, and common pea in integrated and ecological systems under conventional soil cultivation. This is due to the very high nutrient status in the soil, from the beginning of experimental period. Crop rotation in ecological system (37% of leguminous crops) supplemented with farmyard manure does not deplete the soil nutrients within the period of eight years. Generally lower yields under minimum cultivation were caused mainly by higher soil compaction in the top layer (no deeper loosening of soil within 8 years) and in ecological system also by higher weed infestation with domination of perennial weeds (*Cirsium arvense*) and *Amaranthus retroflexus*.

Table 6. Yields of winter wheat in t ha^{-1}.

		System		
Year	**Soil cultivation**	**Ecological**	**Integrated**	**Mean**
1991	Minimum	5.7	6.3	6.0
	Conventional	5.7	6.4	6.0
	Mean	5.7	6.3 a	6.0
1992	Minimum	6.1	6.3	6.2
	Conventional	6.2	6.3	6.3
	Mean	6.2	6.3	6.2
1993	Minimum	3.3	3.1	3.2
	Conventional	3.1	3.5	3.3
	Mean	3.2	3.3	3.3
1994	Minimum	6.6	7.0 a	6.8
	Conventional	6.8	6.9	6.8
	Mean	6.7	7.0 a	6.8
1995	Minimum	5.2	5.9 a	5.5
	Conventional	6.6 B	6.2 A	6.4 B
	Mean	5.9	6.0	6.0
1996	Minimum	6.1	6.6	6.4
	Conventional	6.1	6.8	6.5
	Mean	6.1	6.7	6.4
1997	Minimum	4.7	6.1 b	5.4
	Conventional	5.9 A	6.8	6.4 A
	Mean	5.3	6.5 b	5.9
1998	Minimum	5.2	7.3 a	6.3
	Conventional	6.3	7.0	6.6
	Mean	5.7	7.1 a	6.4
Mean	Minimum	5.4	6.1 b	5.7
	Conventional	5.8	6.2 a	6.0 B
	Mean	5.6	6.2 b	5.9

Significance levels for comparison of systems: a is $P<0.05$, b is $P<0.01$.
Significance levels for comparison of soil cultivation: A is $P < 0.05$, B is $P<0.01$.

Conclusions

This study demonstrated that the rate of C inputs was the most important factor determining the organic matter level in the soil. The increase of soil organic carbon content over the period of 8 years, was observed in both the integrated and ecological systems. Our simple model of carbon balance in agro-ecosystems gave satisfactory results compared to field data. The ecological farming system showed slightly better physical and chemical soil parameters and higher quality of soil organic matter. Regular application of FYM and crop rotation with intercrops in ecological system influenced the biochemical and microbial soil parameters. The highest values of C_{ox}, N_{biol}, daily soil respiration and nitrification were measured in the ecological system.

Differences of crop yields between the systems were greater under minimum cultivation than under conventional tillage. The chemical inputs in integrated system concealed the influence of minimum tillage to the greater extent than in the ecological system. The conventional cultivation in both systems resulted in higher yields. Compared to the integrated system, the ecological system reflected the rotational effect on the winter wheat yield more clearly. The precrop effect of leguminous crop was more yield-promotive for winter wheat in ecological system.

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Impact of cropping system on mycorrhiza

H. Kahiluoto[1] *and M. Vestberg*[2]
Agricultural Research Centre of Finland
[1] *Ecological Production, Partala, FIN-51900 Juva, Finland*
[2] *Laukaa Research and Elite Plant Station, FIN-41330 Vihtavuori, Finland*

Summary

The impact of cropping system on field communities of mycorrhizal fungi was studied utilising a long-term experiment on a loamy soil. Two contrasting crop rotations each with two fertilisation regimes were compared. The conventional crop rotation (barley-barley-rye-oat-potato-oat) was fertilised at either full or half the normal recommended rate. In the low-input crop rotation, one year with barley was replaced by clover, and oat was cultivated in mixture with pea. For this rotation biotite and raw phosphate was used to compensate for the K and P of the harvested yield; animal manure was used at the beginning only. Clover and straw were returned to the soil either directly or after composting. Mycorrhizal infectivity and effectiveness were studied in bioassays in the growth chamber, and the spore densities of mycorrhizal fungi as well as their species composition in the field were determined. Only the low-input system with application of compost conclusively favoured mycorrhiza, in comparison to some or all of the other systems depending on time and function. The low-input system with no compost was more favourable than the conventional systems in terms of growth effect in 1996, but in 1997, clover incorporation markedly inhibited mycorrhiza in comparison to the other systems. Inhibition of mycorrhizal functions may indicate general mismanagement and imbalance in the soil ecosystem. This stresses the need for further studies on the importance of composting easily decomposable organic matter prior to soil incorporation for management of soil quality.

Introduction

In organic agriculture, one management goal is to increase and maintain soil quality with a high biological activity. Mycorrhizal function is an elementary natural process in soil. Mycorrhiza is a symbiosis between most crops and certain soil fungi. It has a major contribution to soil aggregate formation and stabilisation, phosphorus cycling and crop health. Mycorrhiza cause more efficient phosphorus uptake, decreases risk of soil erosion, and reduces the phosphorus leaching. Mycorrhizal functions are, however, very sensitive to human activities. They can be totally suppressed but also remarkably improved by an appropriate cropping system where crop rotation has a marked impact (Dodd *et al*., 1990; Johnson *et al*., 1991).

The possibilities of managing the effectiveness and the diversity of mycorrhizal field communities by cropping systems with varying crop rotations were investigated in a long-term cropping system experiment. The impact of the cropping systems on mycorrhizal infectivity and effectiveness in the original field soil as well as functional potential of fungal populations were determined in bioassays. The influence on fungal community structure was studied through spore morphology in the field.

Materials and methods

Field experiment

A long-term experiment established in 1982 on a loamy soil with two contrasting crop rotations each with two fertilisation regimes, was utilised for soil sampling. There were three complete blocks, each with three different starting points of the rotations. The experiment was located in Ylistaro, Finland (63°N,22°E). The soil properties at the start of the experiment were: pH_{H2O} 5.8, organic C 2.3 % and ammonium acetate-extractable P 5.3 mg l^{-1} (Vuorinen & Mäkitie, 1955). The conventional crop rotation (barley-barley-rye-oat-potato-oat) was either conventionally fertilised (N, P and K 108, 18 and 72 kg ha^{-1} yr^{-1}, respectively) (*system A*) or fertilised with half the conventional amounts of nutrients (*system B*). In the low-input crop rotation, one year with barley was replaced by clover, and oat was cultivated mixed with pea (barley-clover-rye-oat/pea-potato-oat/pea). Animal manure (20 t ha^{-1}) was added once when establishing the experiment. This rotation was fertilised by using biotite and raw phosphate 2-3 t ha^{-1} and 200-300 kg ha^{-1}, respectively, to compensate for the K and P of the harvested yield. Clover and straw were returned to the soil either directly (*system C*) or after composting (*system D*). The average soil P_{H2O} (van der Paauw, 1971) contents in the systems in 1997 were 5.1 (A), 2.9 (B), 1.9 (C) and 2.1 mg l^{-1} (D), respectively.

Bioassay of mycorrhizal infectivity and effectiveness

Soil for the bioassays was collected as composite samples from one stage of the systems, from all the blocks separately. Sampling was performed in the autumns 1996 and 1997, in the growing season with barley and rye, respectively. The preceding crops were oats (A,B) or oats and barley (C,D) for 1996, and barley (A,B) or red clover (C,D) for 1997. *Linum usitatissimum* cv. Linetta (Deutsche Saatveredelung, Lippstadt-Bremen GmbH) was grown as a test plant in the sampled field soil in 1 l PVC pots. The non-mycorrhizal control, with traces of infection in two pots only, was created using benomyl 20 mg (kg $soil)^{-1}$. The pots were organised in three blocks in a growth chamber corresponding to the field blocks. The plants were harvested after four weeks. A representative sample of the root system was cleaned and stained with methyl blue (Grace & Stribley, 1991), and the percentage of colonised root length was determined by the gridline intersect method (Giovannetti & Mosse, 1980). The relative mycorrhizal effectiveness (RME) is presented as the mycorrhizal contribution to the growth of the mycorrhizal plant and defined by the following formula: RME (%) = $[(Y^{myc+}-Y^{myc-})/ (Y^{myc+})] \times 100$ where Y^{myc+} and Y^{myc-} are the dry weights of the mycorrhizal treatment and the control with inhibited AM functioning, respectively.

Spore extraction

Spores were collected in 1995 from every block of two positions in the rotations, from oats (A,B) or oats and pea (C,D) after potato, and from barley after oats (A,B) or oats and pea (C,D). The spores were extracted from field soil by wet sieving and decanting (Gerdemann & Nicolson, 1963) followed by centrifugation in water and in a 50% sucrose solution (Walker *et al.*, 1982). A 500-µm and a 74-µm sieve were used for wet sieving. After centrifugation the spores were transferred into a dish of water for examination under a dissecting microscope at magnifications up to 50 times with illumination by incident light from a fibre-optic, quartz-halogen light source with a colour temperature of 3200 K (Walker *et al.*, 1993). Spores were characterised and, whenever possible, identified to species using a high-power light microscope.

Results and discussion

Infectivity and effectiveness

Mycorrhizal colonisation was relatively low in the bioassay in 1996. It was clearly highest in the soil from the low-input cropping system with plant residues composted before incorporation into soil (D) (mean 22%; range 11-31%). It was lower in the conventional system with half fertilisation (B) (4%; 1-6%) compared with conventional fertilisation (A) (10%; 2-18%) or the low-input system with no compost (C) (11%; 5-15 %). The lower colonisation with half fertiliser rate in the conventional system may be due to decreased carbon supply to the infecting fungi.

Table 1 Impact of cropping system on mycorrhizal effectiveness. A=Conventional system, B= Conventional system with half fertilisation, C=Low-input system and D=Low-input system including composting. RME=mycorrhizal effectiveness or contribution to dry weight. Means of three (1996) or six (1997) replicate pots with ranges in parentheses are presented.

Cropping system	Dry weight $^{myc+}$	Dry weight $^{myc-}$	RME, %
1996, sampling in barley, after oats (A,B) or oats and pea (C,D)			
A	0.171 (0.160-0.176)	0.147 (0.130-0.160)	14
B	0.147 (0.130-0.164)	0.126 (0.115-0.140)	14
C	0.137 (0.110-0.165)	0.094 (0.084-0.108)	31
D	0.156 (0.120-0.205)	0.107 (0.099-0.111)	31
1997, sampling in rye, after barley (A,B) or red clover (C,D)			
A	0.125 (0.115-0.138)	0.094 (0.059-0.119)	25
B	0.119 (0.099-0.130)	0.089 (0.083-0.096)	25
C	0.089 (0.077-0.115)	0.088 (0.078-0.101)	1
D	0.114 (0.101-0.134)	0.078 (0.061-0.087)	32

Like infectivity, the mycorrhizal contribution to dry weight in the bioassay was the highest in the soil from the low-input system with composting (D) both in 1996 and 1997 (Table 1). No difference was observed in either year between the two fertilisation levels of the conventional system. Instead, in soil from the low-input system with plant residues returned uncomposted (C), the effectiveness drastically varied between the two years. In 1996, with a mixture of oat and pea in the field in the preceding growing season, it was as high as with composting, despite of the lower colonisation, while in 1997 it was clearly the lowest. Growth of the mycorrhizal plants, but not of the non-mycorrhizal ones, was also lower than in all the other systems in the latter year, indicating inhibition of mycorrhiza while the plant growth was not directly affected. The uncomposted clover biomass incorporated into the soil the former autumn (1996) had been quickly decomposing in the soil, obviously causing anaerobic conditions and /or toxicity agents unfavourable for mycorrhizal reproduction or functioning. This effect was avoided by composting the biomass before incorporation into the soil.

Mycorrhizal fungal communities

There were no effects of the cropping systems on the functional potential of the mycorrhizal fungal community when inoculated in similar conditions. Differences were, however, observed in spore density. The lowest number of spores was found in the conventional cropping system at both collecting times (Table 2), indicating negative effects on fungal reproduction. In the autumn after the growing season, the highest spore density was in the low-input system with composting (D).

Species richness did not differ between the cropping systems. The most commonly found species were *Glomus claroideum, G. mosseae, Acaulospora scrobiculata* and an unidentified *Glomus*, here called *Glomus "red brown"* (Table 3). These spore types were found in all cropping systems at both collection times. The distribution of spores depended, however, somewhat on the sampling time. For example, *Glomus mosseae* occurred more commonly in soil samples collected in June than in August, while the reverse was true for *G. claroideum*. The lower amounts of *G. mosseae* in August than in June may be due to misidentification. Spores of *G. mosseae* were not mature in August and might therefore have been identified as *Glomus* sp."small white".

Table 2 Impact of cropping system on spore density. A=Conventional system, B=Conventional system with half fertilisation, C=Low-input system and D=Low-input system including composting. Means of six replicate pots with standard deviations in parentheses are presented.

Cropping system	Spring, spores per 100 ml soil	Autumn, spores per 100 ml soil
A	26.3 (9.4)	23.8 (14.3)
B	33.8 (17.8)	33.7 (17.0)
C	32.5 (11.7)	32.8 (21.7)
D	32.2 (14.9)	44.2 (21.0)

Table 3 Impact of cropping system on species composition of mycorrhizal fungi. A=Conventional system, B=Conventional system with half fertilisation, C=Low-input system and D=Low-input system including composting.

	Number of AMF spores per 100 ml soil									
	Cropping system, Spring 1995					Cropping system, Autumn 1995				
Fungus	**A**	**B**	**C**	**D**	**Mean**	**A**	**B**	**C**	**D**	**Mean**
Acaulospora scrobiculata	4	4	4	6	4.5	2	2	4	4	3
Glomus caledonium						0.2				0.1
G. claroideum	7	11	11	8	9.5	8	17	10	16	12.8
G. mosseae	6	10	8	9	8.3	1	3	3	4	2.8
G. rubiformis		0.3	0.2		0.1			0.3		0.1
Glomus sp. "small-white"	2	5	2	2	2.5	12	10	8	13	10.8
Glomus sp "red-brown"	7	5	6	7	6.3	2	2	7	7	3
Glomus spp						0.3				0.1
Scutellospora calospora	0.8	0.2	0.5	0.5	0.5			0.5	0.3	0.2

Conclusion

In conclusion, the low-input system with plant residues composted before incorporation was the most favourable of the systems studied for mycorrhiza. It resulted in the highest spore density in soil, the highest root colonisation and the highest mycorrhizal contribution to growth. There was no conclusive difference between the two fertilisation regimes of the conventional system. The low-input system with no composting was more favourable than the conventional systems in terms of growth effect in 1996, but in 1997 after clover incorporation it remarkably inhibited mycorrhiza in comparison to the other systems. Inhibition of mycorrhizal functions may indicate general mismanagement and imbalance in the soil ecosystem. This stresses the need for further studies on the importance of composting easily decomposable organic matter prior to soil incorporation for management of soil quality.

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Experiments with leguminous crops in a stockless organic farming system with sugar beets

Hans Larsson
Swedish University of Agricultural Sciences, Department of Plant Protection Sciences
Box 44, S-23053 Alnarp, Sweden

Summary

Different leguminous crops were grown for two years and sugar beets were grown the third year after ploughing in the legume crops. Investigations were done on physical parameters like water infiltration and soil resistance with a penetrometer. Spade diagnosis was used for the description of roots and soil structure after the different crops. Nitrogen content in soil and sugar beets was measured and the sugar beet yields were determined.

Medicago sativa, Melilotus officinalis, *Trifolium pratense, Trifolium repens* and the mixture *Trifolium repens* and *Lolium perenne* had the best crop growth and a minimum of weeds. The competition of the crop against weeds is very important in organic farming.

Lower penetrometer resistance especially in the subsoil was observed after *Medicago sativa*, *Melilotus officinalis* and *Trifolium pratense*. Highest resistance was observed after *Lolium perenne*. Water infiltration increased both in topsoil and subsoil with *Medicago sativa, Trifolium pratense, Trifolium repens* and the mixture *Trifolium repens* and *Lolium perenne*.

The spade diagnosis showed high earthworm activity in *Medicago sativa, Trifolium pratense*, *Melilotus officinalis* and *Trifolium pratense*. In the subsoil the best penetration of roots was found with *Medicago sativa*, *Melilotus officinalis* and *Trifolium pratense*. Very good aggregation of the soil was found with *Medicago sativa*, *Melilotus officinalis*, *Trifolium pratense* and *Trifolium repens.*

Sugar beet is a very sensitive crop to soil structure and reacts with a good root development and high sugar yields after leguminous crops. The nitrogen left after the leguminous crops can give too high nitrogen content in the sugar beets and reduce the sugar content. The highest nitrogen content in the soil was found after *Medicago sativa*, *Trifolium repens* and *Trifolium perenne*. The highest sugar yields were found after *Melilotus offficinalis*, *Trifolium pratense* and *Trifolium repens* but good yields were also observed after *Medicago sativa*, *Trifolium pratense* in mixture with *Lolium perenne* and *Onobrychis viciifolia*. Because of the risk for leaching of nitrogen a mixture with legume and grass is recommended in organic farming.

Introduction

The organic crop system in Alnarp, which was established in 1992, is stockless but has red clover or alfalfa in the crop rotation. The legumes are cut and can be used for green manuring. The legumes give a good soil structure and collect nitrogen for the following crops. In order to look at different species appropriate for this use a number of leguminous crops like *Trifolium pratense, Trifolium repens, Medicago* *sativa* and *Melilotus officinalis* were sown in the organic crop rotation in Alnarp and grown for two years. The soil was ploughed in late autumn and sugar beets were grown in the second year. Effects on soil structure and on the production of sugar beets after different species were determined.

Materials and methods

The investigation was carried out in two fields located in Alnarp about 10 km north of Malmö in south-western Sweden. The topsoil is a loam with 18% clay, 2.8% organic matter and pH 7.2. The subsoil is a loamy fine sand of varying thickness with 21% clay, 2.3% organic matter and pH 7.3. The fields are sheltered by hedges of poplar and of natural embankment comprised of various bushes and trees. The field has been conventionally farmed with annual crops for hundreds of years. The fields were converted to organic farming in 1992.

The experiment was set up in a randomised block design with four replicates with a plot size of 15 m × 6 m. The field experiments were done in two identical trials with slightly different soils. The crops were sown in 1995, ploughed in autumn 1996 and sugar beets were grown in 1997. The treatments in the experiment are shown in Table 1.

Table 1 Treatments and amount of seeds ha^{-1}.

Species	Seeds kg ha^{-1}
Onobrychis viciifolia	45
Galega orientalis	36
Medicago sativa	24
Melilotus officinalis	24
Lupinus angustifolia	160
Trifolium pratense	15
Trifolium repens	10
Carum carvi	4
Lolium perenne	10
Lolium perenne + T. pratense	7+3

Legumes, *Carum carvi* and *Lolium perenne* were sown in late spring (May) 1995. *Lupinus angustifolius* is an annual plant and the crop died during the winter 1995/96. *L. angustifolius* was not resown in 1996. Towards midsummer after heading the field was mowed using a haycutter. The harvested material was not removed but left as a green manure on the field. After the first cutting, *Melilotus officinalis* died. The plots were not resown. The crops were cut two or more times during the summer. The fields were not irrigated and no fertilisers were applied. The crop stand was continually assessed for canopy cover and regrowth.

No weeding was done on the trial plots, but the field was mowed at earing and twice thereafter. No mowing was carried out after the month of August.

Measurements of resistance to penetration were carried out during autumn of the seeding year and continuously during the second year. Measurements were done in between the tractor wheel tracts, where compaction due to wheel traffic was expected to be minimal. Measurement was carried out on all plots. A total of 15 insertions were carried out on each plot. Insertion was set to 50 cm depth with readings taken at 1 cm depth intervals.

Canopy cover was determined visually between the mowings. The canopy cover of both crops and weeds were determined. Establishment and vegetation thickness was determined.

Measurement of infiltration rate was carried out on all plots on the topsoil. Measurements were also carried out in the subsoil on two blocks from each of the trial fields. The measurements of infiltration rate were carried out in October 1996 just before ploughing. Within each plot a cylinder (diameter 40 cm, height 20 cm) was driven into the topsoil and filled with water to 15 cm height. The rate of infiltration was then read. For the subsoil the same procedure was carried out after the topsoil was removed.

Profile studies including root studies were carried out in the second year using spade diagnosis. Profiles were lifted from the topsoil of every plot. A spade with a blade width of 19 cm and a length of 30 cm was driven down in the topsoil and the profile was dug out. Using a rake the profiles were then studied and characterised with the coarse structure, fine structure, roots and soil dwelling organisms. Both written documentation, video and camera documentation was used.

Results and discussion

The results of the assessment of vegetation cover carried out in the second year of cultivation are presented in Table 2. The results are divided in two parts. The first part shows the result of the vegetation cover before the first cutting, the second part shows the vegetation cover of the regrowth. In both cases the result of weed infestation also presented.

Table 2 Vegetation and weed cover in different leguminous crops. Average from two experiments in 1997.

	Vegetation cover (%)		Weed cover (%)	
	June	August	June	August
Onobrychis viciifolia	52	58	37	34
Galega orientalis	18	35	60	45
Medicago sativa	96	99	4	1
Melilotus officinalis	95	3	5	80
Lupinus angustifolia	0	0	81	59
Trifolium pratense	97	93	3	6
Trifolium repens	83	95	14	5
Carum carvi	41	44	43	36
Lolium perenne	83	91	6	5
Lolium perenne + T. pratense	97	95	1	4
LSD 0.95	17	14	14	12

With the exception of *G. orientalis* and *L. angustifolia*, the legumes provided adequate vegetation cover. Up to the first cutting the most common weeds were *Taraxacum officinale, Cirsium arvense, Matricaria inodora and Agropyron repens.* In the regrowth, increase in vegetation cover was realised in almost all treatments with legumes with the exception of *M. officinalis* that failed. *M. sativa* had 99% vegetation cover and was the best. The rest of the legume treatments had values between 91-96 %. The most common weeds in the regrowth were *T. officinale, Cirsium arvense* and *Agropyron repens.*

Penetrometer measurements carried out during the summer and autumn of the second year showed reduced resistance in the subsoil under *Trifolium pratense, Medicago sativa, Lupinus angustifolia* and *Melilotus officinalis*. Higher resistance to penetration was measured on treatments with *Lolium perenne*, *Onobrychis viciifolia* and *Galega orientalis.* The highest resistance in the subsoil was measured in *Lolium perenne* (Figure 1).

Infiltration rate measurements from the experimental fields revealed that *M. sativa, T pratense, M. officinalis* and *L. angustifolius* greatly improved the infiltration rate of the subsoil (Figure 2). In comparison to *L. perenne*, leguminous plants had generally higher rate of infiltration. *T. repens* and *L. perenne* both had a fibrous root system and yet there is a big difference in infiltration rate between the two. The infiltration rate was much higher in *T. repens* than in *L. perenne.*

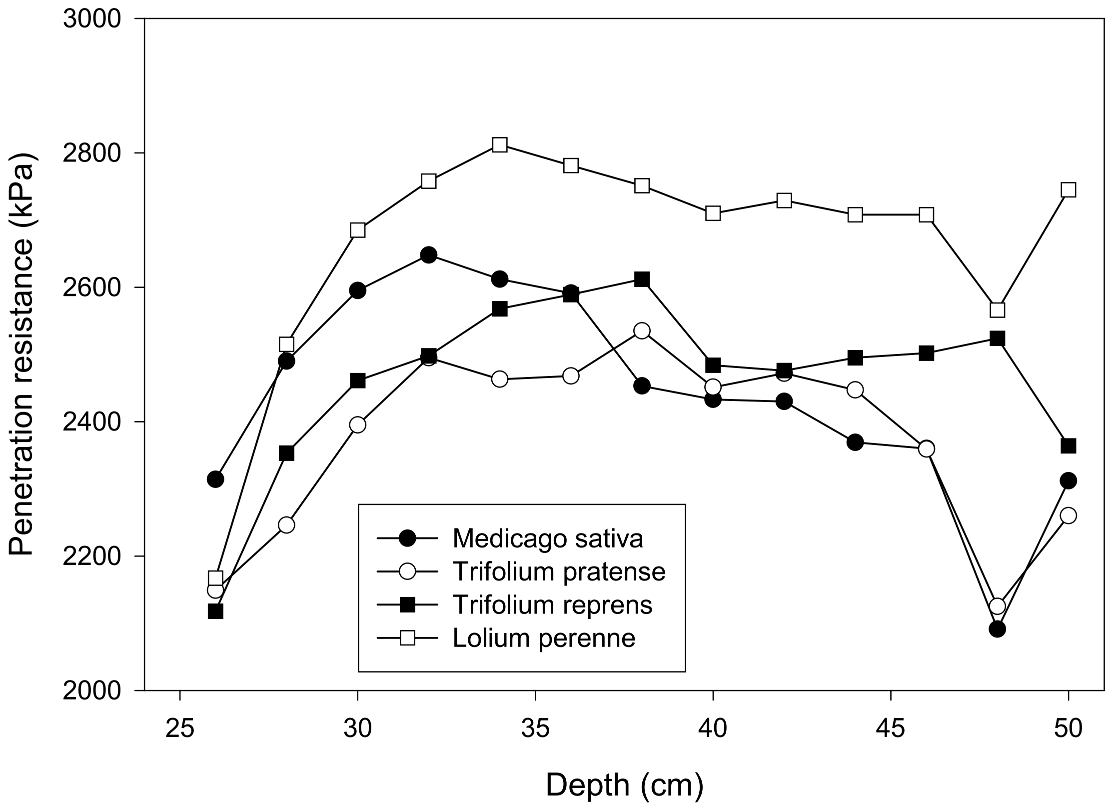

Figure 1 Penetrometer resistance in the subsoil in November.

The result of the spade diagnosis is shown in Table 3. Where mechanical impedance was found in the topsoil, accumulation of the roots in the area of impedance was noticed. Both the vertical and the horizontal distribution of the roots were noticeably reduced over the whole profile of soil. Where mechanical obstacles was found at the base of the plough layer, reduction in root density was noticed even below in the non-tilled layers. At the depths of compacted soil, thickening of the roots (club like) was observed. Branching of roots appeared restricted were mechanically impedition was found. The number of root hairs found on plants was higher in the more compacted soil. In *M. sativa, M. officinalis, T. pratense* and *O. viciifolia* lateral root number appeared reduced. On plots with shallow topsoil and more sandy subsoil flattening of the roots were observed. On *G. orientalis* a zigzaggy growth of the roots was often noticed. In the trial field NF1 the depth of the topsoil varied from about 40cm in block I to about 25 cm in block 1V. Organic matter and clay content also decreased in the same trend in accordance with the depth of the topsoil.

In this study the legumes especially *M.sativa, M.officinalis, T. pratense* and *T. repens* maintained a higher number of earthworms. *O. viciifolia, G. orientalis* and *C. carvi* all maintained lower numbers of earthworms. The mixture *L. perenne* and *T. pratense* maintained surprisingly low numbers of earthworms equal only to that found in the ley grass *L. perenne.*

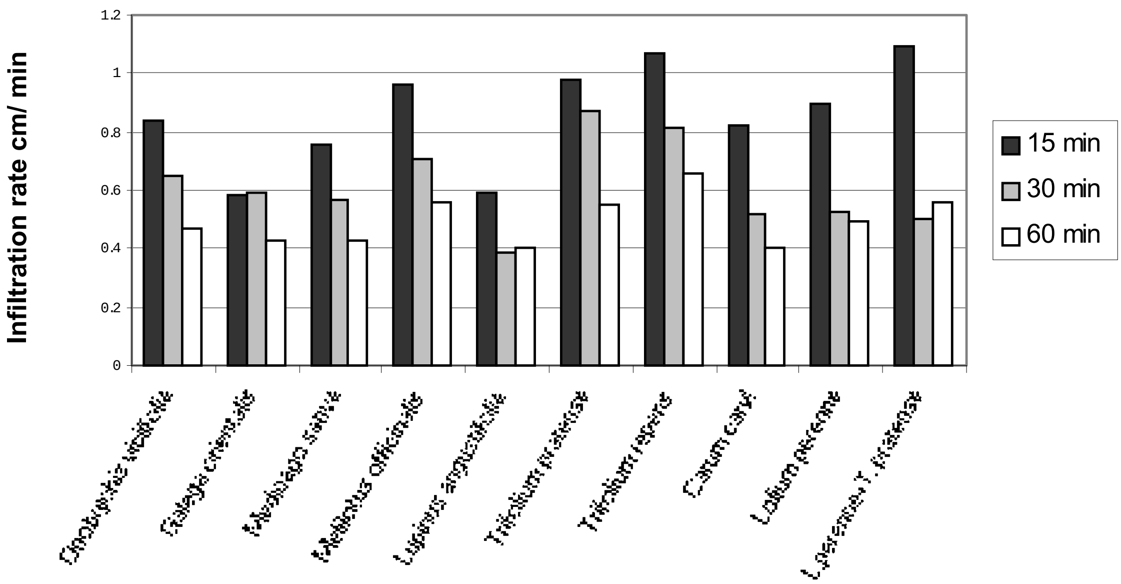

Figure 3 Infiltration of water in the subsoil.

The soil structure was diagnosed for aggregate development, size and types of aggregates, consistence and the presence of pores, cracks, burrows and channels. Root studies including the presence and location of bacterial nodules were also carried out. Legumes clearly improved the formation of aggregates especially in the subsoil (Table 3).

Table 3 Earthworms, roots and soil physical conditions following different leguminous species.

Species	Earthworm (no m^{-2})	E. burrows (no m^{-2})	Roots in topsoil[1,2]	Roots in subsoil[1,2]	Aggregates in topsoil	Aggregates in subsoil	Porosity subsoil
Onobrychis viciifolia	45	Many	Few TR	Few TR	Fine granular	Developed	Medium
Galega orientalis	35	Few	Many FR	Few FR	Fine granular	Weakly developed	Medium
Medicago sativa	90	Very many	Many TR	Many TR	Very fine granular	Very well developed	Very high
Melilotus officinalis	65	Many	Many TR	Many TR	Very fine granular	Well developed	Very high
Lupinus angustifolia	25	Few			Fine granular	Well developed	Very high
Trifolium pratense	75	Very many	Many TR	Many TR	Very fine granular	Very well developed	Very high
Trifolium repens	65	Many	Very many FR	Few FR	Very fine granular	Weakly developed	High
Carum carvi	35	Few	Few TR	Few TR	Granular	Weakly developed	High
Lolium perenne	25	Very few	Very many FR	Few VFR	Granular	None	Low
L. perenne T.pratense	25	Many	Very many FR	Few TR	Very fine granular	Developed	Medium high

[1]: Root density; None (0), Very few (<20 dm^{-2}), Few (20-50 dm^{-2}); Many (50-200 dm^{-2}); Very many (>200 dm^{-2}).
[2]: Root size; VFR (very fine roots, <0.5 mm), FR (fine roots, 0.5-2 mm), MTR (medium thick roots, 2-5 mm), TR (thick roots, >5 mm).

The aggregates of the topsoil were well developed on all plots of the trial fields. The fine granular aggregates were clearly visible with well developed contact surfaces. When handled they fell apart in whole aggregates. In four of the plots however, the topsoil was shallow (about 20 cm deep) resulting in a higher influence from the sandy subsoil reducing the level of aggregate formation in the topsoil in comparison with the rest of the plots.

In the subsoil the most noticeable aggregate developments were found under the legumes. The upper part of the subsoil had well developed aggregates. The dark organic matters, left behind by earthworms, penetrated like polls into the much more light coloured sandy subsoil. Here the mixing action of the earthworms could be seen clearly. Around the roots that penetrated deep into the subsoil, there was tendency to granulation. The study of the difference between the subsoil and the topsoil was made easier on all plots because of the sharp difference between the loamy topsoil and the sandy subsoil below.

The best sugar beet root yields were recorded after *Trifolium pratense, Trifolium repens* and *Medicago sativa* while *Lolium perenne* had the lowest root yield. However, the higher sugar content in the plots after

Melilotus resulted in that *Melilotus* together with *Trifolium pratense* and *Trifolium repens* had the highest net sugar yield. The alfa-amino nitrogen content in the sugar beets reflects the nitrogen content of the soil (Table 4).

Table 4 Harvest results of sugar beets following different leguminous crops. Average from two trials.

Species	Root yield (t ha^{-1})	Sugar (%)	α-amino N (mg 100g^{-1})	Net sugar (t ha^{-1})
Onobrychis viciifolia	58.3	17.6	11	9.2
Galega orientalis	56.1	17.7	9	9.0
Medicago sativa	64.4	16.6	19	9.5
Melilotus officinalis	61.9	17.6	10	9.9
Lupinus angustifolia	56.1	17.6	12	8.9
Trifolium pratense	66.6	16.7	17	9.9
Trifolium repens	67.1	16.6	19	9.9
Carum carvi	54.9	17.7	9	8.8
Lolium perenne	50.1	17.9	8	8.1
L. perenne+T.pratense	60.9	17.2	12	9.4
LSD 0.95	9.0	0.3	4	1.5

Crop protection

Plant protection in an organic crop rotation experiment for grain production

I.A. Rasmussen[1], M. Askegaard[2] and J.E. Olesen[2]
Danish Institute of Agricultural Sciences
[1] Department of Crop Protection, Research Centre Flakkebjerg, DK-4200 Slagelse, Denmark
[2] Department of Crop Physiology and Soil Science, P.O. Box 50, DK-8830 Tjele, Denmark

Summary

The plant protection carried out in the Danish crop rotation experiment is described. These measures can be quite different in the different systems. While mechanical weed control can be carried out in systems without catch crops, it is not possible to do so in systems with catch crops without severely affecting the establishment of the catch crop.

The occurrence of weeds, pests and diseases is recorded, and the results are described. Since the results are only from the two first years of the experiments, it is not possible to make conclusions about the effects of the crop rotations as such. There are, however, differences related to the other experimental treatments in the experiment: the presence or absence of catch crops and manure. Only in very few cases are the differences statistically significant.

Introduction

None of the experimental treatments in the Danish organic crop rotation experiment are directly aimed at plant protection. Within each system, the best possible plant protection is carried out. This means that the plant protection, especially the weed control, in each system can be quite different from the other systems, and also the weed control can differ between locations, since the problems are not identical. The systems can also pose problems regarding plant protection; one example is the occurrence of couch grass (*Elymus repens*) in systems with catch crops. The presence of catch crops prohibits the stubble treatment that is usually the measure used against couch grass. The systems also influence the occurrence of pests and diseases, for example powdery mildew (*Erysiphe graminis*) occurrence on oats is much more pronounced when manure is applied.

Material and methods

The crop rotation experiment is described in Olesen *et al.* (1999) where all combinations of experimental treatments and locations can be seen. In the following, the plant protection measures will be described.

As a general rule, the optimal mechanical weed control is carried out. This includes preventive measures, such as choosing cultivars which are competitive against weeds, placing the manure close to the crop row where possible (Rasmussen *et al.*, 1996) and sowing winter cereals later than what is normally used, preferably around 1st October.

In the spring sown cereals and pulses, where there is no catch crop, weed harrowing is carried out pre- and post-emergence and if necessary, a weed harrowing at one of the later growth stages is used (Rasmussen & Rasmussen, 1995).

In winter cereals without catch crops, pre- and post-emergence harrowing is carried out after sowing, if the weather permits and if the harrowing can be carried out without covering more than at most 10% of the crop surface with soil, and one or several weed harrowings are carried out in the spring. These measures proved not to be sufficient on the sandier soils. Therefore since 1998 the winter cereals in rotation 4 at Foulum and the spring and winter wheat and the lupins (since 1999) at Jyndevad have been sown at larger row distances to facilitate mechanical hoeing between the rows (Rasmussen & Pedersen, 1990).

In the winter wheat with catch crops, except for rotation 4, weed harrowing is carried out in the fall (if possible) and in the spring before sowing of the catch crop. At Jyndevad, mechanical weed control is carried out pre- and post-emergence before the catch crop is sown in all cereal and pulse crops. In rotation 4, the white clover and weeds between the rows of winter wheat are cut down several times during the season with a row brush hoe.

The sugar beets are kept weed free by a strategy of pre-emergence flaming, row and hand hoeing.

If perennial weeds such as creeping thistle (*Cirsium arvense),* mugwort *(Artemisia vulgaris),* curled dock *(Rumex crispus)* and others occur, they are removed manually from the plots. In the case of creeping thistle this is done by cutting the stalk as deep under ground as possible at the time of the anthesis of the cereals, which coincides with the time when the thistles are budding. At this time the reserves in the root system are at a minimum (Dock Gustavsson, 1997). If couch grass (*E. repens)* occurs in plots without catch crops above a threshold level of 5 shoots m^{-2}, or white clover (*Trifolium repens)* occurs in plots without catch crops, repeated stubble cultivation is carried out after harvest. If couch grass occurs in plots with catch crops above a threshold level of 50 shoots m^{-2} stubble cultivation will be carried out. Another measure to cope with couch grass is to intensify the cutting of the green manure grass-clover. Without occurrence of couch grass the cutting is carried out when the grass-clover has a height of about 15-20 cm in mixtures without red clover (at the sandier soils) and about 20-25 cm in mixtures with red clover (at the loamy soils). With occurrence of couch grass in the crop preceding grass-clover above a threshold of 5 shoots m^{-2}, the cutting is carried out when the grass-clover has a height of about 10-15 cm and 15-20 cm, respectively.

Weed occurrence is monitored in cereals and pulses around the time of anthesis (growth stage 59, Lancashire *et al.*, 1991). The three dominating weed species and the remaining weeds in each plot are counted, dried and weighed in 3 samples of 0.25 m^2. Shoots of couch grass are counted in five samples of 0.1 m^2 each approximately 2 weeks after anthesis and the occurrence of this weed is also assessed in the whole plot at this time and after the growing season. Number and location in the plot of creeping thistle and other perennial weed plants are registered if present at the time of their hand weeding, and if applicable, again after harvest.

Choosing crop cultivars that have a high degree of resistance against the most important diseases, wherever possible prevents plant diseases. In order to avoid seed borne diseases all seed material is tested prior to sowing, and seed lots that are prone to display seedborne diseases are rejected. In rotation 4, with two subsequent years of winter wheat, there have been very severe attacks of take-all *(Gaumannomyces graminis)* at Foulum and Flakkebjerg. Because of this, the second year winter wheat has since 1999 been substituted by winter triticale at Foulum, as this is expected to be less damaged by take-all.

One measure taken again insect pests is to sow the beets at a plant density of 21 plants m^{-2}, which is twice the final plant density. If up to 50% of the germinating beets are devoured by insects, then it is still possible to reach the desired plant density. Another measure taken to prevent leather jackets (*Tipula paludosa*) is that the grass-clover sward at the sandier soils is left uncut in a period between 15 August (where the grass must be at least 10 cm high) 15 and September. The flies prefer to lay their eggs in short grass during this period.

The most common and serious diseases and insect pests are monitored twice in wheat and triticale and once in the other cereals and pulses and when applicable in the beets. The occurrence of leaf disease in the cereals (mildew (*E. graminis*), net blotch (*Drechslera teres*) and scald (*Rhyncosporium secalis*) in barley and oats and brown rust (*Puccinia hordei*) in barley; mildew (*E. graminis*), yellow rust (*Puccinia striiformis*), glume blotch (*Septoria nodorum*) and leaf spot (*S. tritici*) in wheat and triticale) is registered as the percent coverage of the two or three top leaves on ten plants two places in each plot. Takeall (*G. graminis*) is monitored on 25 plants of wheat and triticale dug up with roots. Leaf diseases (beet virus yellows, mildew (*Erysiphe betae*), rust (*Uromyces betae*) and ramularia (*Ramularia beticola*)) on the beets are registered as percentage plants with the disease on twenty plants. Occurrence of insect pests (aphids (*Rhopalosiphum padi, Sitobion avenae* and *Metopolophium dirhodum*) in cereals and cereal leaf beetles (*Oulema melanopus* and *O.lichenis*) in barley and oats; pea weevil (*Sitonia lineatus*) in peas, lupins and undersown clover and pea aphids (*Acyrthosiphon pisum*) in peas and lupins; field thrips (*Thrips angusticeps*), pygmy beetles (*Atomaria linearis*) and aphids (*Aphis fabae* and *Muzus persicae*) in sugar beets) is registered as the percentage of shoots/plants injured or habitated in each plot or as a grade of insect devouring two places in the plot.

Results and discussion

Weeds

The greatest amount of weeds, in numbers as well as biomass, was found on the sandier soils (Figure 1). The most common species were chickweed (*Stellaria media*), fat-hen (*Chenopodium album*) and shepherds purse (*Capsella bursa-pastoris*) at Jyndevad, scentless mayweed (*Tripleurospermum inodorum*) and chickweed at Foulum, black bindweed (*Polygonum convolvolus*) and chickweed and in 1998 creeping thistle (*C. arvense*) at Flakkebjerg and scentless mayweed in 1997 at Holeby.

At all locations and in both years the greatest amount of weeds occurred in the winter wheat (Table 1). For the spring sown crops, the pea/barley mixture was most infected with weeds at all locations in 1997. Oats was among the crops with the lowest amount of weeds at all locations in both years. In both years there was a tendency for more weeds, in numbers as well as biomass, in the fertilised treatments at Foulum and Flakkebjerg (Table 2). At Jyndevad, there was a tendency for most weed biomass in the unfertilised treatments in the winter wheat in 1997.

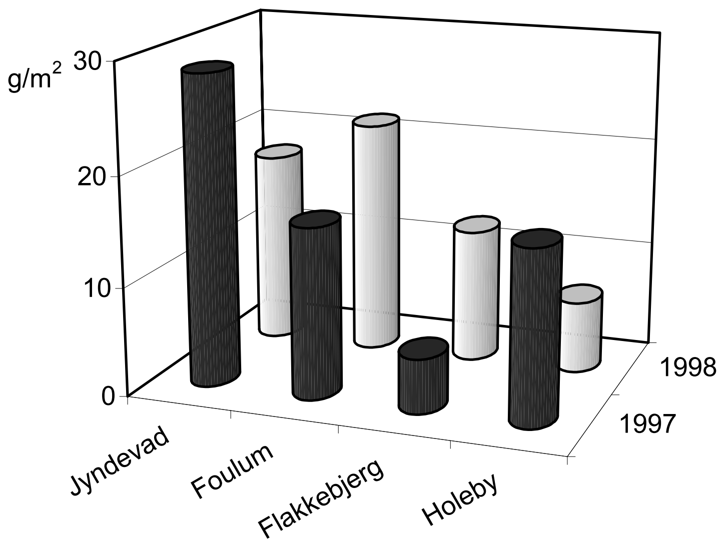

Figure 1 Biomass of weeds at the four locations in two years.

Table 1 Biomass (g m^{-2}) of weed in the different crops.

	Jyndevad		Foulum		Flakkebjerg		Holeby	
Crop	**1997**	**1998**	**1997**	**1998**	**1997**	**1998**	**1997**	**1998**
Pea/barley	30	13	11	16	3	13	5	8
Spring barley	21	16	6	16	3	13	2	6
Winter wheat	35	27	25	32	8	15	31	8
Oats			7	10	2	14	4	4
Lupin		15						
Spring wheat		21						

Table 2 Weed biomass (g m-2) in crops with (+) or without (-) manure.

		Barley		Winter wheat		Oats		Spring wheat	
Location	**Manure**	**1997**	**1998**	**1997**	**1998**	**1997**	**1998**	**1997**	**1998**
Jyndevad	-	20	17	43	23	-	-	-	20
	+	22	14	28	31	-	-	-	21
Foulum	-	6	13	21	17[2]	3	4	-	-
	+	6	19	29	45[2]	11	16	-	-
Flakkebjerg	-	1	5	4[1]	9	3	5	-	-
	+	4	15	11[1]	19	2	21	-	-

Levels of significance: [1]: $P<0.05$, [2]: $P<0.01$.

Table 3 Biomass (g m^{-2}) of annual weeds with different weed control in winter and spring wheat. Results in the same row with the same (or no) index letter are not significantly different at the 5% level.

	Weed control			
Location	**Harrowing only before sowing of catch crop**	**Weed harrowing**	**Brush weeding**	**Row hoeing**
1997 – winter wheat				
Jyndevad	31	39	-	-
Foulum	44^{a}	24^{b}	16^{b}	-
Flakkebjerg	8	8	-	-
1998 – winter wheat				
Jyndevad	38	-	-	16
Foulum	27^{bc}	23^{c}	55^{ab}	16^{c}
Flakkebjerg	11	13	19	-
1998 – spring wheat				
Jyndevad	23	-	-	19

In the winter wheat in 1997, the weed control was very successful at Foulum, with significant differences in the weed biomass of treatments with full weed harrowing or brush weeding, as compared to weed harrowing carried out only before the sowing of the catch crop (Table 3). At Jyndevad, there was a tendency towards more weed biomass with the full weed harrowing, while there were no differences at Flakkebjerg, where there was not a very strong weed pressure. In 1998, the brush weeding at Foulum was less successful than all the other treatments, while row hoeing was the most successful there as well as at Jyndevad. The differences were smaller at Flakkebjerg, but the brush weeding treatment resulted in the most weed biomass. The differences in spring wheat at Jyndevad in 1998 were very small.

Table 4 Biomass (g m^{-2}), number m^{-2} of annual weeds and yield with different weed control in oats.

	Weed biomass g m^{-2}		Weed density number m^{-2}		Yield (85% dry matter) hkg ha^{-1}	
Location	**None**	**Weed harrowing**	**None**	**Weed harrowing**	**None**	**Weed harrowing**
1997						
Foulum	11	3	91	58	36	31
Flakkebjerg	3	1	70[3]	16[3]	36	23
1998						
Foulum	16	4	81	29	53	49
Flakkebjerg	15	11	80	47	38	37

Significant differences between weed control within location, year: [3]: P<0.001.

Table 5 Percentage of plots with couch grass (*E. repens)* in spring or winter sown cereals and pulses with (+) and without (-) catch crop and the average number of shoots found in plots with couch grass.

Crop sown	Catch crop	Jyndevad % of plots	Jyndevad shoots m^{-2}	Flakkebjerg % of plots	Flakkebjerg shoots m^{-2}	Holeby % of plots	Holeby shoots m^{-2}
Spring	-	35	17	6	34	20	2
	+	40	12	22	5	-	-
Winter	-	50	19	33	7	50	24
	+	50	16	50	8	-	-

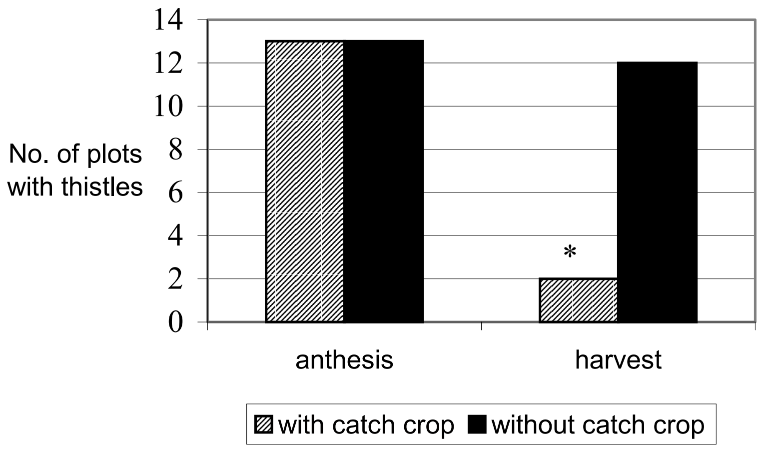

Figure 2 Number of plots with thistles at anthesis and after harvest in Flakkebjerg 1998. At harvest there are significantly more plots with thistles without a preceeding catch crop.

The differences of weed biomass with different weed control measures in the pea/barley mixture and lupins were not very large and in no case significant.

The treatments with weed harrowing in oats in all cases reduced the biomass as well as the numbers of the weeds, in one case significantly (Table 4). However, the yield was also reduced. It should be noted that the effects of weed harrowing cannot be separated from the effects of the catch crop, because the catch crop effect was confounded with the weed harrowing treatments such that plots without a catch crop were harrowed and those with a catch crop were not.

In 1998, couch grass (*E. repens*) was found at three locations. The weed was never found in all plots of any one crop, but at Jyndevad it was almost exclusively found in block two, and in most of the plots. In several cases the threshold for stubble treatment was exceeded in plots without catch crops (Table 5). The threshold has not yet been exceeded in plots with catch crops, but this could happen soon. To preserve the effect of the catch crop, the stubble treatment in plots with catch crops might be a shallow plowing followed by sowing of a fast growing competitive crop, such as fodder radish (*Raphanus sativus*). The decision of how to carry out the treatment is not final.

In 1998 creeping thistle (*C. arvense*) was found at Flakkebjerg. At harvest the thistles appeared significantly more often in plots without a preceding catch crop than in plots with a preceding catch crop. At anthesis they had appeared in equal numbers of plots with or without preceding catch crops (Figure 2).

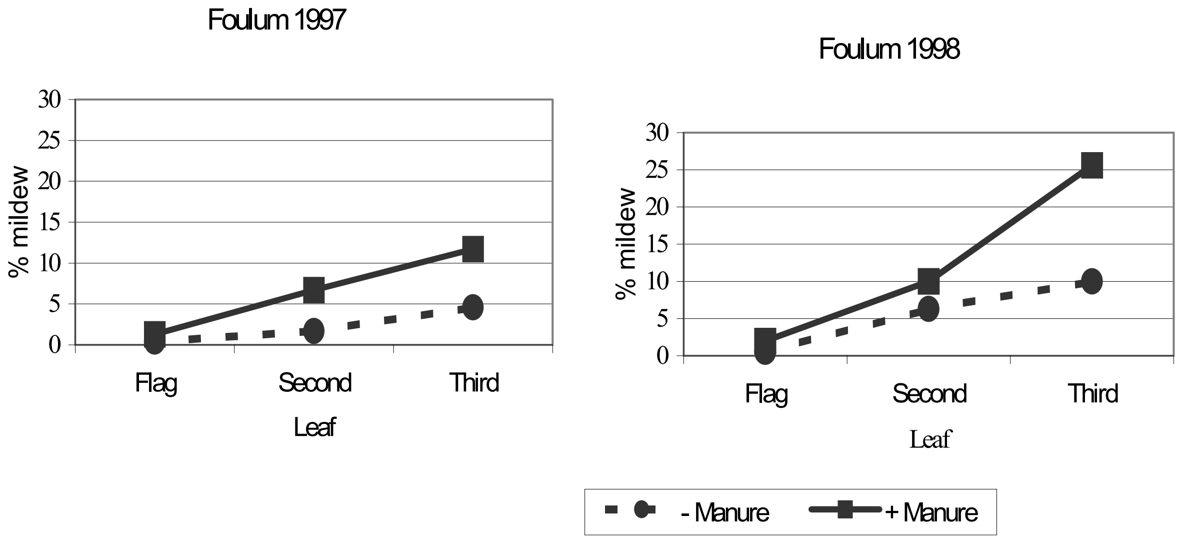

Figure 3 Attack of mildew, % leaf coverage, in oats with (+) and without (-) manure.

Table 6 Percent leaf coverage of septoria in wheat at two registration times.

		First registration (growth stage 59)		Second registration (2-3 weeks later)	
Location	**Year**	**Flag leaf**	**Second leaf**	**Flag leaf**	**Second leaf**
Winter wheat					
Jyndevad	1997	0	1	5	16
Foulum	1997	0	0	8	29
Jyndevad	1998	1	1	2	12
Foulum	1998	0	0	2	11
Flakkebjerg	1998	0	0	30	80
Spring wheat					
Jyndevad	1998	0	0	16	20

Diseases and pests

The attack of leaf diseases on the cereals has not been very severe in 1997 and 1998, except for powdery mildew (*E. graminis)* in oats and Septoria (*S. nodorum* or *S. tritici)* in wheat and in 1998 mildew (*E. graminis)* in spring wheat. The attack of mildew in oats was worst in the treatments that had received manure (Figure 3). The attack of septoria (Table 6) in wheat was most severe at the latest registration, but there were no differences between treatments. In 1998, the attack was much worse at Flakkebjerg compared with the locations on the sandier soils. In the spring wheat, 40% of the leaves were covered with mildew in the middle of July (growth stage 70). A better protection against diseases may be obtained through the of use a mixture of different varieties. This would increase the resistance of the crop against diseases, because the different varieties could represent different levels of resistance against different diseases, and also because the resistance could be based on different genes. The reason this is not done is that it would make many of the registrations of growth stage, disease level etc. more difficult (Askegaard *et al.*, 1999).

Table 7 Percent roots of wheat with take-all (*G. graminis*).

	Crop rotation			
	1	**2**	**3**	**4**
1997				
Jyndevad	8	16		
Foulum		7		5
Flakkebjerg		1	0	1
Holeby		4	0	0
1998				
Jyndevad*	1	3		
Foulum		2		15
Flakkebjerg		3	3	11
Holeby		0	0	0

* Spring wheat in rotation one.

Table 8 Percent roots with take-all in second year winter wheat in rotation 4 in 1998 with (+) or without (-) manure and with and without catch crop.

Location	Manure	No catch crop	Catch crop
Foulum	-	26	25
Foulum	+	19	41
Flakkebjerg	-	22	18
Flakkebjerg	+	14	29

Take-all (*G. graminis)* was found at all locations in both years. In 1997 the attack was worst at the sandier soils (Table 7). Apparently the combination of the preceding crop of spring barley and the sandier soils was conducive to the disease, whereas the loamy soils, in spite of a long history of cereals, did not react as profoundly. At Foulum, the experimental area had different cropping history. In the area, where there had been grass within three years before the experiment, only 1% or less of the roots was infected with take-all. In the area, where grass had not been grown within five years before the experiment, 22% of the roots were infected. In 1998, the heaviest attacks were found in rotation 4, where one out of two years of winter wheat had a preceding crop of winter wheat. In the other rotations there were not very severe attacks, and it appears that one year of grass-clover was the reason for this. At Holeby, even rotation 4 was not very affected. In the second year winter wheat in rotation 4, where the heaviest attacks were found, there was interaction between the manure and the catch crop (Table 8). Without manure, the difference between the attack with and without catch crop was small, but with manure, the attack was twice as severe with catch crop as without. It was expected that the attack would be worst with catch crop, since this system was not ploughed between the two years of wheat.

In the sugar beets at Holeby in 1998, there were rather severe attacks of mildew (*E. betae)* (35% plants attacked), rust (*U. betae*) (90 % plants attacked) and ramularia (*R. beticola*) (50 % plants attacked) in September. At Flakkebjerg, the diseases were seen, but less than 10% of the plants were attacked by the end of September.

In 1997, there were no serious attacks by insect pests in the cereals. On the sandier soils the winter wheat had attacks of aphids (*R. padi, S. avenea* or *M. dirhodum)* on up to 64% of the shoots in July (growth stage 72-75). The attacks on the loamy soils were below 15% of the shoots. In 1998, up to 87% of the shoots of pure spring barley at Jyndevad were infested with aphids by the end of June (growth stage 59), while the attacks at the other locations were around 10% or less. The attacks on the spring barley grown in mixture with peas were less than 20%. In oats, 24-38% attacks were found at the same growth stage at Foulum and Flakkebjerg. In the winter wheat, up to 38 % of the plants had aphids at growth stage 59, and 2-3 weeks later op to 86% were attacked, and in the spring wheat 75% of the shoots had aphids at growth stage 59, but they had all disappeared 2-3 weeks later.

An insect pest that could be feared in systems, where nitrogen fixing plants is the main source of nitrogen, is the pea weevil (*S. lineatus*) which not only harms the plants by eating the leaves, but also devour the nodules containing the nitrogen fixing bacteria on the roots. In 1997, up to 25% of the leaf area of the peas had been eaten 10 days after germination, while there appeared to be much less infection in the undersown clover. In 1998, the attacks were registered on a scale of 1-10, and did not pass 2 in the peas at any location. The attacks were less in the undersown clover, and not found at all in the lupins. In 1997, up to 38% of the peas were infected with aphids at Holeby, with attacks below 5% at the other locations. In 1998, no location had above 16% attack and the lupins only 1%.

In the sugar beets, there were heavy attacks of pygmy beetles (*A. linearis*) at Holeby in both years. In 1997, where the crop was sown at final plant density, the beetles reduced this very much. In 1998, 50% of the plants were damaged, but this was not as severe, since there were twice as many plants as needed for the final plant density.

The plant protection carried out in the Danish crop rotation experiment has not been sufficient to avoid the presence of weeds, pests and diseases. In some cases, there has been a tendency towards a difference between the treatments. It is still premature to conclude on any effects of the crop rotations or the other experimental treatments in the experiment. In addition to this, the experimental treatments may themselves influence the results of the crop protection: for example the presence of a catch crop reduces the possibilities of mechanical weed control.

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Plant residues for weed management in vegetables

L.O. Brandsæter[1] and H. Riley[2]
The Norwegian Crop Research Institute
[1] Plant Protection Centre, Department of Herbology, Fellesbygget, N-1432 Ås, Norway
[2] Apelsvoll Research Centre div. Kise, N-2350 Nes på Hedmark, Norway

Summary

Both one and two applications of fresh grass-clover mulch controlled weeds germinating from seed, which dominated in this white cabbage experiment. There was little extra benefit from mulching twice compared to once, but this finding needs verification before more general advice can be given. For weed control it is generally an advantage to leave the mulch undisturbed on the soil surface. Rototilling causes seeds in the soil to germinate. An inferior effect may be expected against perennial weeds after mulching, compared to that which was obtained against annual weeds.

Introduction

Weed control and nutrient supply are key factors for the successful production of vegetables in organic farming. The use of mulching and/or legume cover crops (e.g. living mulch) is one possible approach for optimising these key factors. Experiments in Norway, in which white clover(*Trifolium repens* L.) or subterranean clover (*T. subterraneum* L.) were used as living mulch in white cabbage (*Brassica oleracea* L. convar c*apitata* (L.) Alef. var. *alba* DL.)have shown benefits both in relation to weed suppression and green manuring effects on the crop during the subsequent year (Brandsæter *et al.*, 1998). Additionally, this study showed beneficial control effects on cabbage root fly (*Delia radicum* L.), turnip root fly (*D. Floralis* Fal.) and caterpillars, primarily *Mamestre brassicae* L. However, the competition between the cover crop and cabbage was considerable. A main concern in living-mulch cropping systems is yield depression because of competition. Screening experiments aimed at finding more suitable cover crops have been initiated in Norway (Brandsæter & Netland, 1999). An alternative approach, which does not cause such competition problems, is surface mulching with harvested legume material, produced on an adjacent area to that of the vegetables. The present experiment included factors such as amount of legume material and the choice between incorporating the debris into soil with a rototiller or leaving it on the soil surface. This paper includes only the presentation of weed assessments, whereas yield assessments have been presented by Riley & Brandsæter (1999).

Materials and methods

In 1997 the crop was barley undersown with a mixture of red clover (*Trifolium pratense* L.) cv. Bjursele (4 kg ha^{-1}), and *Phleum pratense* L. cv. Grindstad (14 kg ha^{-1}), and *Festuca pratensis* Huds. cv. Fure (8 kg ha^{-1}). The barley was harvested and the cover crop was left to grow throughout the autumn.

In the spring of 1998 the field was used both for the experiment and for production of clover material (approx. 75% red clover and 25% grasses) for use in the experiment.The field was ploughed on 4 May.

The experimental design was a randomised two by three factorial split plot, with three replications. Debris (mulch) on the soil surface or incorporated into soil were the two main treatments. Zero, one, or two applications of mulch were subplot treatments.These treatment-plots are later referred to as follows:

A. Control, no mulch and no fertiliser after the incorporation of the previous year's cover crop.
B. Mulched once on 11 June with a 3-cm layer of fresh grass-clover mixture.
C. Mulched twice, on 11 June and on 2 July with 3-cm layers of fresh grass-clover mixture.

The experiment was carried out in white cabbage cv. Eton. The crop was planted at 40 cm spacing in double rows, giving 33300 plants per ha. The cabbage was harvested on 6 October with harvest plots of 12 m^2.

Nutrient addition and soil analysis

Cover crops of clover and grasses were harvested by a forage harvester and transferred to a tractor-mounted dispenser carrying the necessary volume (900 l) to cover each double-row with a 3-cm layer. The total amount of nitrogen added as clover was 330 and 590 kg ha^{-1} in the B and C plots, respectively.

Weed recordings

Separate species recordings and counts of all weeds were performed in quadrats (44 × 44 cm) randomly placed at 4 different locations within a 2 m wide row in each plot. The counting quadrats were placed between the cabbage-rows.Weeds were recorded twice, on 1 July and 21 July. Weed plants were dried at 60°C for 72 h before weighing.

Most weed species had 2-4 true leaves at the first mulch-application, on 11 June.It is also worth noticing that incorporation (by rototilling) of the mulch (and just rototilling in plot A) was carried out 10 days after the first mulching. The first weed recording occurred one and a half week after rototilling.

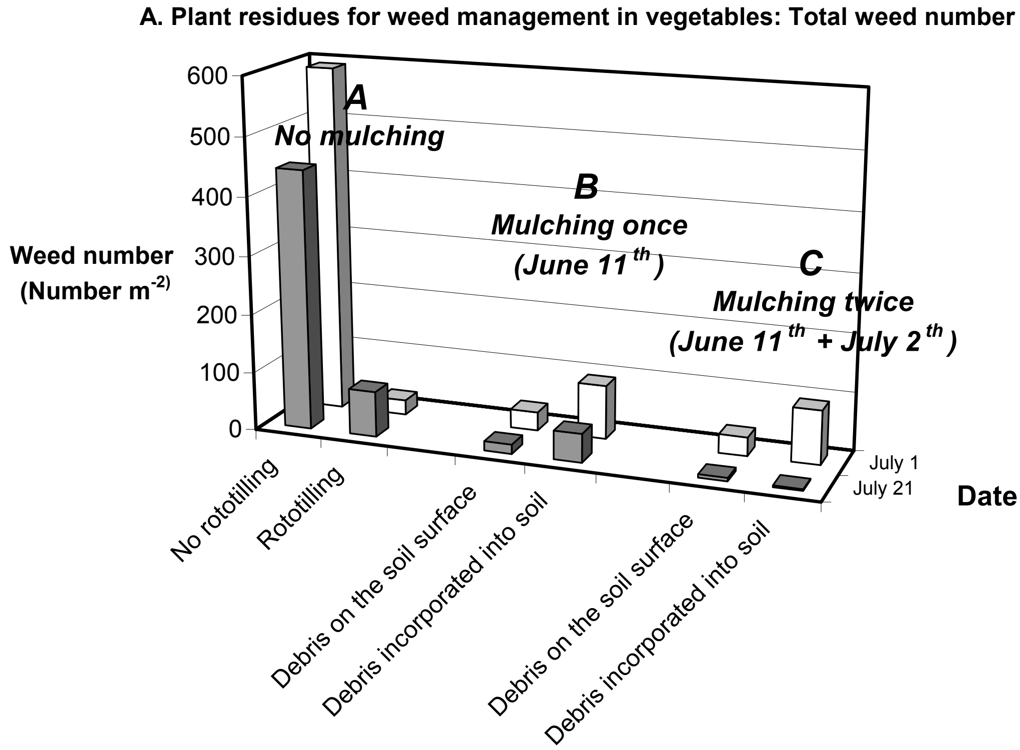
In the following section, results from all weed species are summed in order to give the total numbers of weeds and total weed biomass.

Results and discussion

Occurrence of weeds

Statistical analysis of results from both dates shows that both mulching and rototilling significantly reduced the amount of weeds. Both the grass-clover mulch and rototilling effectively reduced the amount of weeds in the period when the cabbage crop tolerates least competition.

Both one and two applications of mulch controlled weeds effectively. Results from both weed-counting dates show that there was not much to gain by mulching twice, compared to mulching only once.



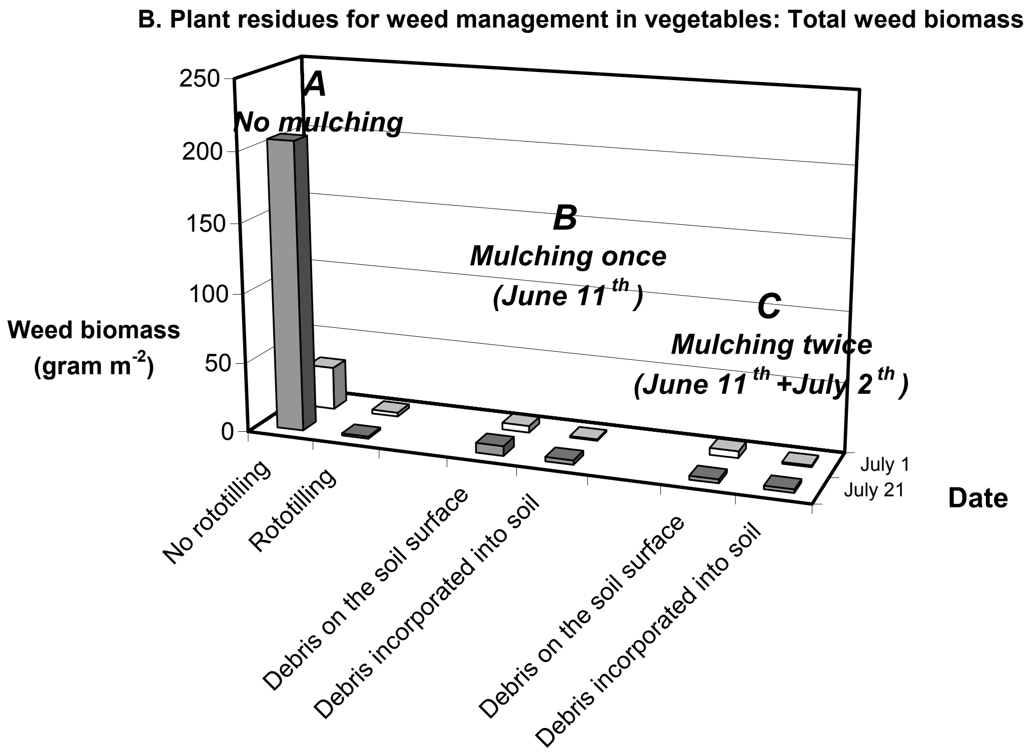


Figure 1 Plant residues for weed management in vegetables; (A) Total weed number, and (B) Total weed biomass.

As expected, rototilling was efficient in controlling weeds. This was also the case in the unmulched plots. In plots with mulch and rototilling combined, the number of weeds was higher than in corresponding plots without rototilling. For weed control it is therefore better to leave the mulch undisturbed at the soil surface. The explanation for that is that rototilling stimulates seeds in the soil to germinate.

When considering only the weed-control effect, the results indicate that rototilling is equally efficient as mulching with clover. This is, however, only half the story, since the rototiller in use can only control weeds growing between the plant rows in the first part of the growing season. On the other hand, the clover mulch controlled weeds equally effectively both in and between the rows. For methodical reasons, weeds were only counted between the rows.

Table 1 Yields and NPK content of mulch material used in the experiment, as well as the required growing area and the quantities of NPK added at different times in B and C plots.

Yields and content of NPK	**Total yield kg ha^{-1}**	**DM content (%)**	**DM yield kg ha^{-1}**	**N-content % of DM.**	**P-content % of DM.**	**K-content % of DM.**
12 June (B and C plots)	32 240	14.5	4 680	2.48	0.22	1.14
2 July (C plots)	57 280	11.8	6 760	2.19	0.20	1.15
Amounts of different matters supplied	Fresh weight kg m^{-2}	Dry weight kg m^{-2}	Area needed m^2 m^{-2}	N-amount kg ha^{-1}	P-amount kg ha^{-1}	K-amount kg ha^{-1}
12 June (B and C plots)	9.33	1.35	2.88	334	30	154
2 July (C plots)	9.83	1.16	1.71	253	23	133

It has previously been observed that different weed species react differently to varying mulch cover thickness (Brandsæter, 1996; Mohler & Teasdale, 1993). In USA Mohler and Teasdale found that some species, like *Taraxacum* sp. and *Stellaria media* L., germinated both better and faster under thin mulch covers, e.g. 100 g dry matter m^{-2}, than without mulch.With thicker mulch covers, like 500 g dry matter m^{-2}, germination of all species was much reduced.The trials by Mohler and Teasdale and others (e.g. Almeida,1985), have shown that a mulch cover density of 500 g dry matter m^{-2} or more is needed for efficient weed control.

In our study, the mulch levels B and C received 1350 g m^{-2} and 1350 + 1160 g m^{-2} respectively. Table 1 shows that the area needed for mulch production was 2.88 times the area mulched. This means that for growing 1 ha of cabbage, you need another 3 ha for mulch production. This land requirement corresponds to what has been found in Finland by Jaakkola (1995). If one application of mulch in the middle of June is enough, then the area used for mulch production can be reused for other crops later in the season.

Use of clover mulch in sufficient amounts as a ground cover is efficient in controlling weeds that germinate from seed. Perennial weed species are not expected to be controlled equally well. The exact rate of mulch biomass needed for efficient weed control depends on several factors such as weed species composition, weed development stage at mulching, the rate of mulch decomposition and the competitiveness of the main crop, which depends on species, fertilisation etc.

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Effect of green manure crops on root rot and arbuscular mycorrhizal fungi in pea roots

L. Bødker[1] and K. Thorup-Kristensen[2]
Danish Institute of Agricultural Sciences
[1] Department of Crop Protection, Research Centre Flakkebjerg, 4200 Slagelse, Denmark
[2] Department of of Fruit, Vegetable and Food Science, 5792 Årslev, Denmark

Summary

Two years field trials have shown that green manure crops are able both to increase and suppress root rot of green peas (*Pisum sativum*) and the root colonization of the pathogen resting spores (oospores) of *Aphanomyces euteiches* depending on the year. However, use of oil radish (*Raphanus sativus*) which in the first year with field trials significantly reduced disease incidence, but in the second year increased the disease incidence, emphasize the importance of studies in disease suppressive mechanisms and validation trials of green manure crops over several years. Additionally, the trials showed that green manure crops influence the prevalence of mycorrhizal fungi in the roots. There was even a tendency that the use of *Brassica campestri* spp. *rapifera,* which is a non-mycorrhizal crucifer, increased the arbuscular mycorrhiza colonization of the roots of the succeeding pea crop. However, the difference in root colonization with natural mycorrhizal fungi cannot explain the difference in pathogen colonization with oospores as seen in previous studies.

Introduction

Legumes are of great importance in organic plant production both as break crops in general and because of their biological nitrogen fixation.

Soil-borne diseases can be a serious problem in intensive crop rotations and especially in pea (*Pisum sativum*) where the build up of root pathogens can be a major threat for the sustainable legume production. Common root rot of pea caused by *Aphanomyces euteiches* is one of the major limiting soil borne pathogens in pea production world wide (Oloffson 1967; Papavizas & Ayers, 1974; Kraft *et al.*, 1994, Persson *et al.*, 1997). If visible symptoms are recognised in the field, it implies that enough resting spores (oospores) are produced to restrict further pea growing for at least 10-15 years. In organic plant production, it is therefore crucial to avoid the build up of soil-borne inoculum by exploitation and stimulation the natural biocontrol mechanisms in the field.

Much effort has been turned into cropping systems, which reduce high levels of soil infestation. To achieve a more efficient disease control, it is important to focus on the fields which have no serious infestation and in these fields prevent further build up of soil borne pathogens.

Many organic substances have a disease suppressive effect on many soil-borne diseases. The mechanisms involved in disease suppression are numerous and often unknown. One of potential mechanisms is the pre-colonisation of the roots by mycorrhizal fungi. However, the efficiency of mycorrhizal fungi as a biocontrol agent is still questionable as the effect may vary from disease suppression to disease enhancement depending upon plant, mycorrhizal and pathogen species and cultural and environmental conditions (Dehne, 1982; Perrin, 1990).

The purpose of this paper is to show the effect of green manure crops on the severity of root disease and root colonisation of mycorrhiza on pea.

Materials and methods

In an organic field, 2 cm of soil naturally infested with *A. euteiches* were mixed into the top soil (0-12 cm) with a rotary cultivator before sowing the green manure crops *Vicia villosa, Pisum sativum*, S*ecale cereale*, *Avena sativum, Raphanus sativus* and *Brassica campestri* spp. *rapifera* in four replicate plots. The *R. sativus* crop was ploughed under in November. The other green manure crops were mixed into the soil around 1 April. In the spring of 1997, pea (c.v. Ambassador) was sown after each of the green manure crops. The trial was repeated in 1997/98. Samples were collected five times from plant emergence to full flowering stage. Each sample consisted of 10 plants taken at random from each plot. Plants were gently dug up removing excess soil. Plants were cut at the cotyledons and fresh and dry weights of plant top were measured. The remaining root system was washed by gently rubbing under running tap water and scored for disease severity.

Roots were dried between sheets of paper towels and cut into 1.5 cm segments. The roots were cleared and stained (Kormanik *et al.*, 1980) and the percentage root infection by *A. euteiches* and the colonisation by indigenous AM fungi were estimated by the grid-line intersect method (Giovannetti & Mosse, 1980; Rosendahl, 1985).

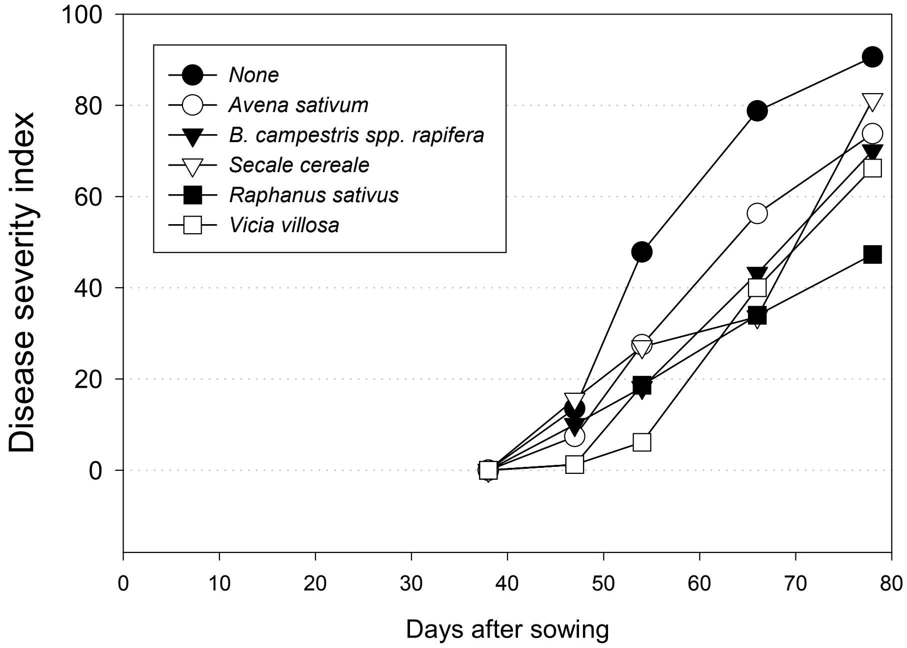
The logit transformation was used for disease index, % Aphanomyces and % mycorrhiza. The variables were analysed using a generalised linear model in SAS system (SAS, 1996a,b).

Results

I both years, a significantly lower disease level was observed where green manure crops had been mixed into the soil before sowing the peas (Figure 1, Table 1). However, the results were not reproducible as *R. sativus* lead to the lowest and highest disease severity, respectively in the two years. *B. campestri* spp. *rapifera* on the other hand, reduced disease severity both years (Figure 1).

Table 1 Table of significance (P values) for effects of treatments on four different variables.

	1997					1998				
	38	47	54	66	78	22	35	42	49	56
Disease index	-	0.06	0.05	0.21	0.10	0.45	0.45	0.72	0.04	0.04
% Aphanomyces	-	0.03	0.07	0.59	0.04	-	0.45	0.03	0.02	-
% Mycorrhiza	-	-	-	-	-	0.64	0.14	0.62	0.35	-
Dry weight	0.24	0.62	0.03	-	0.56	0.07	0.28	0.04	0.56	0.06



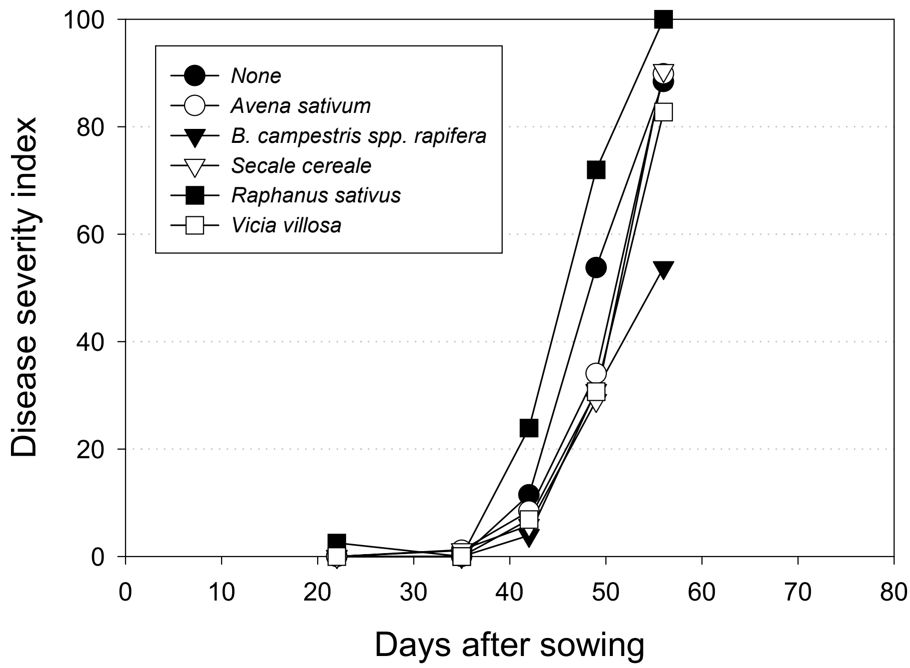
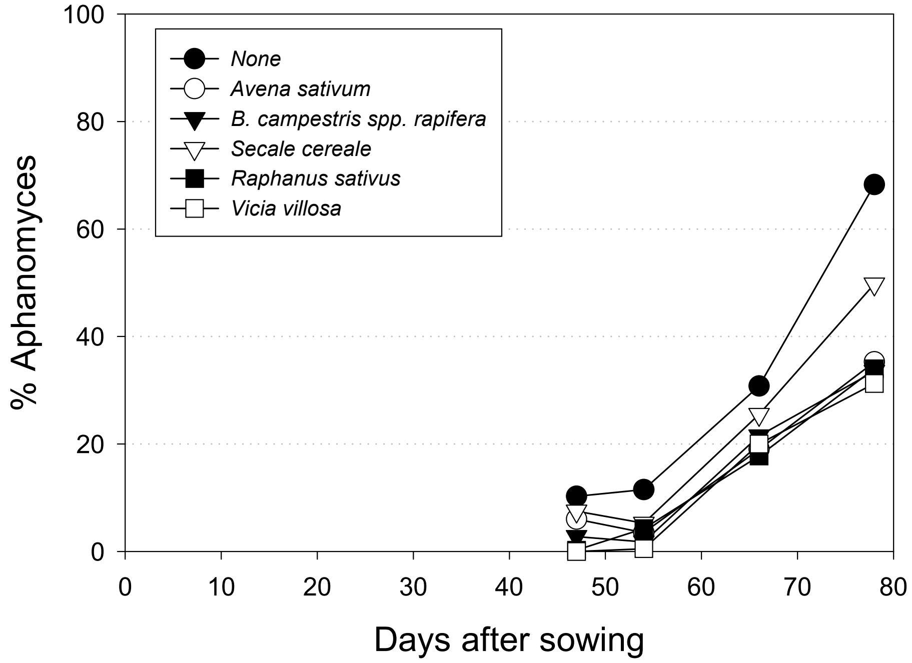


Figure 1 Percent severely diseased roots (>60% discoloration) in pea roots as function of days after sowing for five different green manure crops, a) 1997 b) 1998.



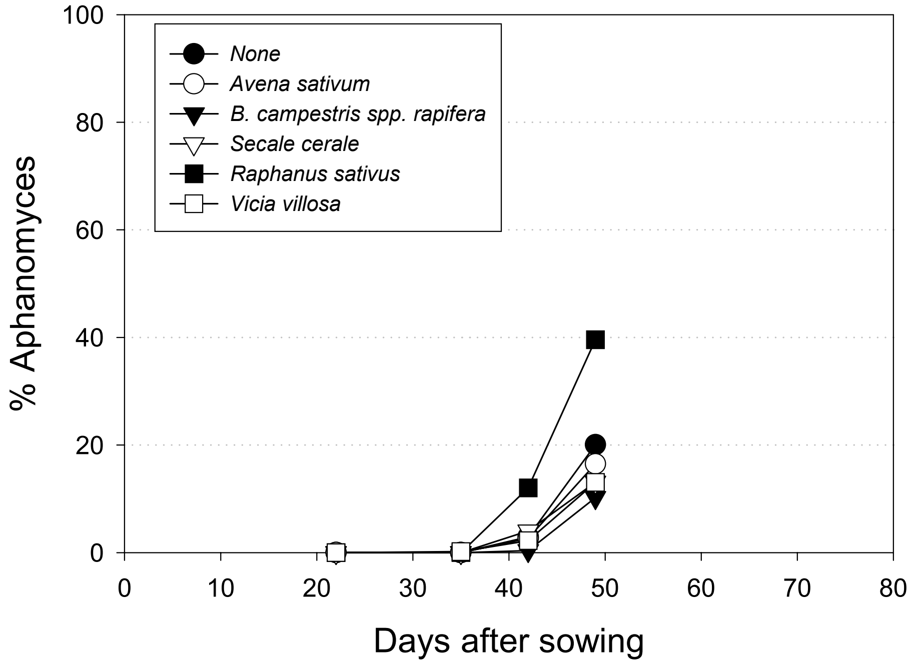


Figure 2 Percent root colonisation of oospores of *Aphanomyces euteiches* in pea roots as function of days after sowing for peas following five different green manure crops, a) 1997 b) 1998.

The colonisation of pea roots with oospores of *A. euteiches* (Figure 2) followed the same trend as the general disease severity (Figure 1).

The symbiotic mycorrhizal fungi are also influenced by addition of organic substances. There was a tendency, that green manure crops increased the colonization of mycorrhizal fungi in the roots (Figure 3). However, there were no significant differences between treatments (Table 1)

In 1997, there was very little influence of green manure crops on top dry weight. At the harvest at full flowering in 1998, there was a significant lower top dry weight where no green manure had been grown than when peas were grown after the green manures, even after *R. sativus* which had increased disease severity this year (Figure 4).

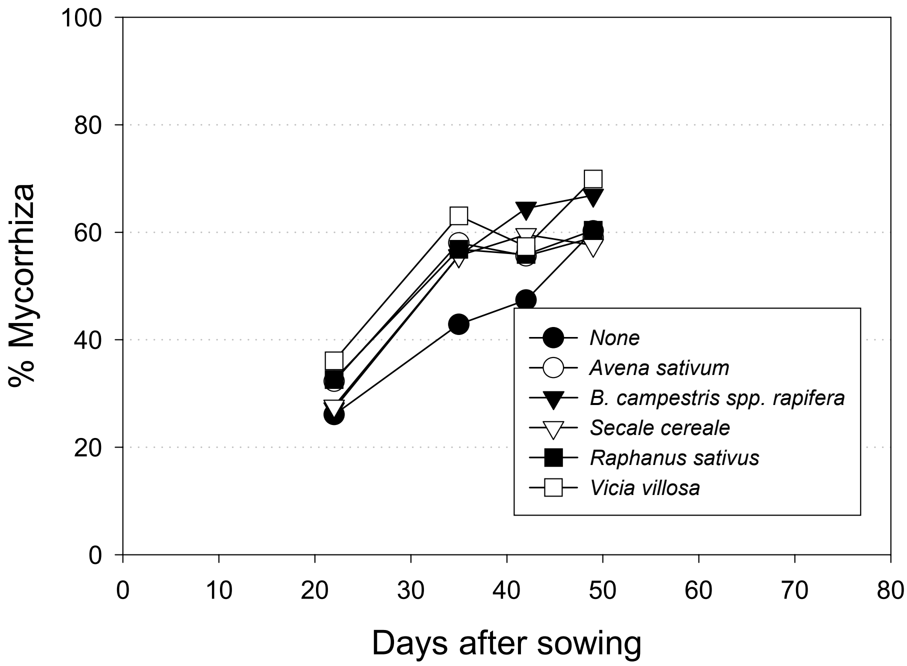


Figure 3 Percent root colonisation of arbuscular mycorrhizal fungi in pea roots as function of days after sowing for peas following five different green manure crops in 1998.

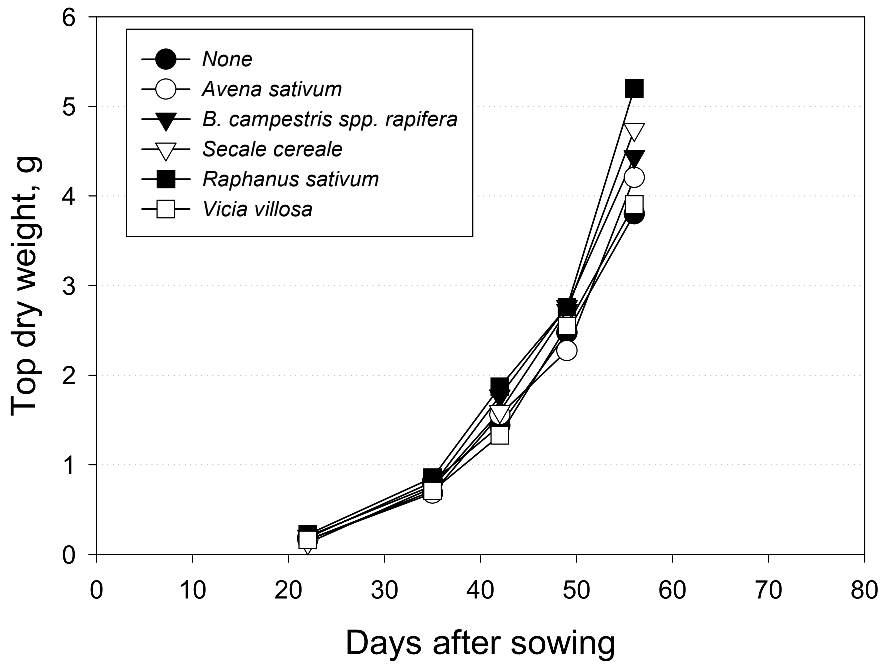


Figure 4 Dry weight of aerial plant parts of pea plants as function of days after sowing for peas following five different green manure crops in 1998.

Discussion

Since the beginning of the 1960's many reports have shown that crucifers can reduce the disease severity of root rot in pea caused by *A. euteiches* (Papavizas, 1966; Papavizas & Lewis, 1971; Chan & Close, 1987; Muelchen *et al.*, 1990). In this paper, it is shown that *B. campestri* spp. *rapifera* has a potential for reducing root rot according to these earlier findings. However, use of *R. sativus* shows contradictory results for disease severity and oospore colonisation in the two respective years. There is no obvious explanation for this discrepancy other than variation in precipitation and temperature, which may have influenced the release of toxic substances or the build up of an antagonistic microflora differently in the two years.

In 1998, there was a tendency for a generally higher colonisation of mycorrhizal fungi in pea roots after green manure crops. Even after the use of *B. campestri* spp. *rapifera*, which is a non-mycorrhizal crucifer the pea roots showed higher mycorrhizal colonisation. However, there was no correlation between mycorrhizal colonisation of pea roots and the infection with oospores of *A. euteiches*.

Most reports show a disease suppressive effect of most organic amendments. However, these two years of field trials clearly showed that it is possible both to increase and suppress root pathogens by using green manure crops. Several mechanisms are involved when organic amendments affect occurrence of root diseases. Which ones becomes the most important in a specific situation may be related to many edaphic factors and the specific pathogens involved. The results from these two field trials emphasise the importance of studies in disease suppressive mechanisms and validation trials of green manure crops over several years.

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Participants

Åsmund Asdal
Norwegian Crop Research Institute
Division Landvik, 4886 Grimstad, Norway
+47 37257700
+47 37257710
aasmund.asdal@planteforsk.no

Margrethe Askegaard
Danish Institute of Agricultural Sciences
Dept. of Crop Physiology and Soil Science
P.O. Box 50, 8830 Tjele, Denmark
+45 89991702
+45 89991719
Margrethe.Askegaard@agrsci.dk

Magdalena Lacko Bartosova
Department of Agricultural Systems
Slovak Agricultural University
Tr.A.Hlinku 2, 94976 NITRA, Slovak Republic
+421 87 601205
+421 87 511560
bartosov@afnet.uniag.sk

Lars Olav Brandsæter
Planteforsk Plantevernet
Fellesbygget, 1432 Ås, Norway
+47 64949400
+47 64949226
lars.brandsater@planteforsk.no

Lars Bødker
Danish Institute of Agricultural Sciences
Department of Plant Protection
4200 Slagelse, Denmark
+45 58113300
+45 58113301
lars.bodker@agrsci.dk

Enio Campiglia
Department of Crop Production
University of Tuscia, S. Camillo de Lellis street
01100 Viterbo, Italy
+39 0761 357554
+39 0761 357558
campigli@unitus.it

William F. Cormack
ADAS Terrington, Terrington St. Clement
Kings Lynn, Norfolk PER34 4PW, UK
+44 1553 828621
+44 1553 827229
Bill_Cormack@adas.co.uk

Laurie E. Drinkwater
Rodale Institute
611 Siegfriedale Rd.,
Kutztown, PA 19530, USA
+1 610-683-1437
+1 610-683-8548
ldrink@rodaleinst.org

Ragnar Eltun
The Norwegian Crop Research Institute
Apelsvoll Research Centre
2858 Kapp, Norway
+47 61166900
+47 61166901
ragnar.eltun@planteforsk.no

Jørgen Eriksen
Danish Institute of Agricultural Sciences
Dept. of Crop Physiology and Soil Science
P.O. Box 50, 8830 Tjele, Denmark
+45 89991870
+45 89991719
Jorgen.Eriksen@agrsci.dk

Mike Gooding
Department of Agriculture
The University of Reading
Earley Gate, P.O. Box 236
Reading RG6 6AT, United Kingdom
+44 118 931 8487
+44 118 931 8297
M.J.Gooding@reading.ac.uk

Romana Holle
Ökoring,
Kieler Strasse 26
24582 Bordesholm, Germany
+49 4322 699 833
+49 4322 759 444
oekoring.sh@t-online.de

Henning Høgh-Jensen
Laboratoriet for Planternes Ernæring
Institut for Jordbrugsvidenskab, KVL
Thorvaldsensvej 40
1871 Frederiksberg C, Denmark
+45 3528 3391
+45 3528 3460
hhj@kvl.dk

Lars Stoumann Jensen
Laboratoriet for Planternes Ernæring
Institut for Jordbrugsvidenskab, KVL
Thorvaldsensvej 40
1871 Frederiksberg C, Denmark
+45 3528 3470
+45 3528 3460
lsj@kvl.dk

Erik Steen Jensen
Agro-Ecology
Department of Agricultural Sciences, KVL
Agrovej 10, 2630 Taastrup, Denmark
+45 3528 3517
+45 3528 2175
esj@kvl.dk

Steve A. Jones
Department of Agriculture
The University of Reading
Earley Gate, P.O. Box 236
Reading RG6 6AT, United Kingdom
+44 118 969 1804
+44 118 969 1804
S.A.Jones@reading.ac.uk

Helena Kahiluoto
Agricultural Research Centre of Finland
Partala, 51900 Ona, Finland
+358 15 651064, +358 40 5118335
+358 15 3212350
Helena.Kahiluoto@mtt.fi

Ulrich Köpke
Institute of Organic Agriculture
University of Bonn
Katzenburgweg 3, 53115 Bonn, Germany
+49 228735616
+49 228735617
iol@uni-bonn.de

Hans Larsson
SLU, Box 44
23053 Alnarp, Sweden
+46 40 415255
+46 40 462166
Hans.Larsson@vsv.slu.se

Ralf Loges
Department of Organic Farming
Christian-Albrechts-University of Kiel
Holzkoppelweg 2
24118 Kiel, Germany
+49 431 880 4654
+49 431 880 4568
rloges@email.uni-kiel.de

Gunnar Mikkelsen
Danish Institute of Agricultural Sciences
Dept. of Crop Physiology and Soil Science
P.O. Box 50, 8830 Tjele, Denmark
+45 8999 1667
+45 8999 1619
Gunnar.Mikkelsen@agrsci.dk

Paul Mäder
Forschungsinstitut für biologischen Landbau
(FiBL), Ackerstrasse, Postfach
5070 Frick, Switzerland
+41 62 8657272, +41 62 8657232
+41 62 8657273
paul.maeder@fibl.ch

Kurt Möller
Technische Universität München
Lehrstuhl für Phytopathologie
85350 Freising, Germany
+49 8161 713739
+49 8161 714538
k.moeller@lrz.tum.de

Wytze Nauta
Louis Bolk Institute, Hoofdstraat 24
3972 LA Driebergen, The Netherlands
+31 343 - 517814
+31 343 - 515611
W.Nauta@louisbolk.nl

Jørgen E. Olesen
Danish Institute of Agricultural Sciences
Dept. of Crop Physiology and Soil Science
P.O. Box 50, 8830 Tjele, Denmark
+45 8999 1659
+45 8999 1619
JorgenE.Olesen@agrsci.dk

Frank Oudshoorn
Danish Institute of Agricultural Sciences
Rugballegaard, Postbox 536
8700 Horsens, Denmark
+45 7560 2211 - 206
+45 7562 4880
FrankW.Oudshoorn@agrsci.dk

Gabriel Paunescu
Agricultural Research Station
Str. Sos. Balcesti nr. 14
Simnic-Craiova - Jud. Dolj, Romania
+40 51419104, +40 51417534
+40 51417534

Lois Philipps
Elm Farm Research Centre
Hamstead Marshall, Newbury
Berkshire RG20 OHR, UK
+44 1488 608898
+44 1488 658503
EFRC@Compuserve.com

Gabriele Pietsch
Institut für Ökologischen Landbau
Universität für Bodenkultur
Gregor Mendel Strasse 33
1180 Wien, Austria
+43 1 47654 3764
+43-1 47654 3792
gpietsch@edv1.boku.ac.at

Ilse A. Rasmussen
Danish Institute of Agricultural Sciences
Department of Plant Protection
Research Centre Flakkebjerg
4200 Slagelse, Denmark
+45 5811 3394
+45 5811 3301
IlseA.Rasmussen@agrsci.dk

Hans-Jürgen Reents
TU Muenchen-Weihenstephan
85350 Freising, Germany
+49 8161 71 3778
+49 8161 71 4419
reents@serv.agrinf.agrar.tu-muenchen.de

Harald Schmidt
Chair of Organic Agriculture
Department of Agiculture and Environment
Protection, University of Giessen
Karl-Glöckner-Str. 21 C
35394 Gießen, Germany
+49 6419937735
+49 6419937739
Harald.Schmidt@agrar.uni-giessen.de

Kristian Thorup-Kristensen
Danish Institute of Agricultural Sciences
Dept. of Fruit, Vegetable and Food Science
P.O. Box 102, 5792 Aarslev, Denmark
+45 63904128
+45 65992598
Kristian.ThorupKristensen@agrsci.dk

Peter von Fragstein
University of Kassel
Department of Ecological Agriculture
Nordbahnhofstr. 1a
37213 Witzenhausen, Germany
+49 5542 981 567
+49 5542 981 568
pvf@wiz.uni-kassel.de

Christine Watson
SAC, Land Management Department
Environmental Division
Craibstone Estate, Bucksburn
Aberdeen AB21 9TQ, UK
+44 1224 711143
+44 1224 711299
C.Watson@ab.sac.ac.uk

Frank Wijnands
Exp. Station of Arable Farming
P.O. Box 430
8200 AK Lelystad, The Netherlands
+31 3200 30479
F.G.Wijnands@PAV.AGRO.NL

David Younie
SAC Agronomy Department
Craibstone Estate
Bucksburn, Aberdeen AB21 9YA
United Kingdom
+44 1224 711072
+44 1224 711293
d.younie@ab.sac.ac.uk

Livija Zarina
State Plant Breeding Station Priekuli
Zinatnes street 1A, Priekuli
4126 Cesis, Latvia
+371 4130162, +371 4130242
+371 4130162
pr_sel@apollo.lv

About DARCOF

Organic farming aims at many of the problems of today's farming: consideration of environment and nature, animal welfare, product quality and health are fundamental aspects of organic farming.

Promoting organic farming - including a boost in research - has therefore been part of the government policy for several years. In the light of that, the Danish Research Centre for Organic Farming (DARCOF) was established at the end of 1996 with the purpose of co-ordinating and promoting the co-operation within organic farming.

DARCOF is a "centre without walls" meaning that scientists remain in their own environments but work across institutions. Presently the activities at Research Centre for Organic Farming comprise 15 institutes and around 100 scientists.

The research co-ordinated by DARCOF is intended to develop organic farming in order to enable the farmers to make a profit while at the same time showing consideration for the environment thus making it easier to change from conventional to organic farming. The research should be of high quality and at an international level. It should be comprehensive, i.e. comprise both organic, social and economic conditions and it should be based on the ideas and problems of organic farming.

Research programs

At present, 33 research projects are in progress under the auspices of DARCOF. The projects are related to the following six main fields:

I. Strategic and basic activities in organic farming concentrating on biological and environmental aspects
II. Production-oriented research and development tasks in organic farming
III. Development and research activities in the organic plant production
IV. Organic plant production
V. Organic pork
VI. Knowledge synthesis and research education in organic farming

As a consequence of the general idea and the interdisciplinary nature of organic farming, great importance has been attached to the co-operation between the projects both within and among the four programmes.

Organisation

DARCOF is managed by a board with representatives from the Danish Institute of Agricultural Sciences, the Danish Veterinary Laboratory, the Institute of Agricultural and Fisheries Economics, Risø National Laboratory, the Royal Veterinary and Agricultural University, and the National Environmental Research Institute. In order to secure the contact to the relevant user groups, a user committee has been established with representatives from different organisations with an interest in this research.

Facilities

In order to ensure a coherence of the research projects within organic farming, the projects are to a great extent carried out at the research facilities connected to DARCOF. These are mainly:

Organic research station

At Research Centre Bygholm, Rugballegård was established as an organic research station where organic livestock production and the correlation between animal husbandry and crops in a large total area could be examined. In 1996, Rugballegård was officially authorised for organic farm production, and new stalls have been built, e.g. pig houses with outdoor areas. The farm comprises 140 ha divided into three different crop rotations: a cattle crop rotation, a pig crop rotation, and a mixed crop rotation with cattle and pigs.

Test and workshop areas

At the research centres in Flakkebjerg, Årslev and Foulum, as well as on Jyndevad and Askov Test Farms, a total of 55 ha of test and workshop areas have been established. These areas are mainly intended for plant studies, including trials with crop rotations and are managed in accordance with organic principles. In these areas, it is possible to carry out analytical tests demanding different types of soil and climatic conditions.

Private organic farmers

Finally, agreements have been made with private organic farmers who make their farms available for research activities.

Danish Research Centre for Organic Farming
Foulum • P.O. Box 50 • DK-8830 Tjele
Tel. +45 89 99 16 75 • Fax +45 89 99 12 00
E-mail: foejo@agrsci.dk
Homepage: www.foejo.dk