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Mixed Farming Systems in Europe

Workshop Proceedings, Dronten, The Netherlands
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Preface

The development of farming systems and their implementation is more and more a major task for agricultural research. Awareness of the insustainability of many farming systems that were stimulated during the last decennia gave rise to a renaissance of mixed farming systems research. In this workshop the state of the art in this field is given. It is shown how technologies and systems based on better insight may contribute to the achievements of multiple goals. Productivity, environmental goals such as efficiency of use of external inputs and ethical goals such as animal well-being are better served in these new systems.

Not for reasons of nostalgia or for reasons of conservation these new mixed farming systems are developed, but for reasons of the conviction that multiple goals are better attainable when such mixed systems are developed. These systems may be made operational at different scale levels. In this compilation of various studies, it is clearly illustrated how many studies at various scale levels may be instrumental for the ultimate goal of the design, development and implementation of sustainable farming systems. Studies at regional level, at farming systems level, at cropping systems level and detailed process observations at crop level are given in these Proceedings of the first Workshop on Mixed Farming Systems in Europe. Farming systems with various levels of rigidity of constraints are described and it is stimulating to see how many different studies take place at various places in Europe.

The Scientific Advisory Committee of the Mixed Farming Systems Research at the Wageningen Agricultural University is indebted to Sjaak Wolfert, Jules Bos and Tanja de Koeijer for taking the initiative to organize this Workshop. The proceedings are carefully edited and the relatively short length of the contributions may be very useful to gain a good impression of the state of the art in this rapidly developing research field on mixed farming systems.

Wageningen,
May 1998

Rudy Rabbinge
Chairman Scientific Advisory Committee

Contents

MIXED FARMING: A WAY TO SUSTAINABILITY

Sustainability, risk perception and the perspectives of mixed farming systems

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Introduction

Sustainable development is concerned with a long-lasting relationship between human beings, the environment and nature. It is a concept that has now largely become a symbol that nobody cares to oppose. Many people have, therefore, seen the importance of defining the concept more precisely and have made efforts in that direction. This has resulted in a large number of highly divergent interpretations, the latest estimate resulted in some 274 definitions. Generally speaking these approaches assume that the boundaries between a sustainable and non-sustainable development can be unambiguously determined, in other words that it is possible to define for example sustainable agriculture in a scientifically objective way, using concepts such as carrying capacity. That is, however exceptionally difficult and impossible when the link between sustainable development and human activity occurs (WRR, 1995). Even when, for example, sustainable agriculture is described as an agriculture that uses the non-renewable resources with care, replaces the renewable resources such that no depletion of the resource base occurs and the ecological values are maintained. The description is still very ambiguous. Ambiguous because insights on ecological values and impacts, on the spatial scale of cycling nutrients and resources, and on the need to renew resources at various time scales may be different. Risks perceptions dominate outcome of such considerations.

In the absence of clear-cut criteria, the strategy to attain sustainable agriculture has to make use of normative interpretations. These interpretations have different judgements on the perception and acceptance of various risks, i.e. societal risks and ecological risks. To make that operational, four action perspectives were developed by the WRR (1995), that illustrate the possible differences in normative attitudes when making a trade-off between human activities and the effects of those activities for the environment. A certain risk perception need not be adhered to once and for all, human beings are capable of learning and altering their stance in response to fresh information. The abstract reasoning in terms of ecological and societal risks is clearly different in: Utilizing, Saving, Managing and Preserving (Table 1). These four action perspectives aim at sustainability as explicitly mentioned in their intention, but the weighing of ecological and societal risks differs, and

Table 1. Four action perspectives aimed at the achievement of sustainable development. (Source: WRR, 1995).

	Consumption	
Production	High	Low
Adaptation of production methods	Utilizing	Saving
Change in nature of production methods	Managing	Preserving

flexibility and possibilities for change are different.

The *Utilizing* action perspective is based on confidence in the resilience of the environment. By contrast, the ability to influence social dynamics by policy measures is considered limited. Environmental problems need to become urgent before sufficient energy can be mobilized in society to urge solving that problem. This approach places particular reliance on technological solutions.

In the *Saving* action perspective, confidence in the resilience of the environment does not extend across the board. On the account of the enormous growth in the scale of human activities, the continuity of those activities is even regarded as under threat in the long-term. A cut in living standards is, therefore, required, which is where policy comes to bear. The possibilities for applying technology must not be overestimated.

Under the *Managing* action perspective, the risks to the ecological system are avoided as far as possible. This is, however, subject to the condition that the rise in living standards is largely left undisturbed. Under this perspective, the social risks of rigorous intervention are regarded as so great as to call into question the legitimacy of such intervention. More so as 80% of the world community is still living at a standard far below the standard generally accepted in the industrialized world and their consumption pattern is rapidly changing. Although the Managing perspective does provide for some moderation of consumption, the solutions are primarily sought in the technological sphere.

The *Preserving* action perspective exhibits little confidence in the resilience of the environment, for which reason adjustments are required to economic and other social activities that impose a burden on the environment. Measures can be brought to bear both in the field of consumer behaviour and with respect to the production system. Ultimately, the necessary social willingness is deemed to exist under this perspective.

World food supply and food security

These four action perspectives were elaborated on a global level and take the form of asking, for example, in case of the world food situation, whether the rapidly growing world population could potentially be fed and whether the agricultural methods with which this would have to be done can satisfy various ecological objectives. In this respect, a distinction has been drawn in the consumption sphere between a relatively 'luxurious' and a more 'moderate' food package (Table 2). More specifically, the moderate food package is largely vegetarian, with once or twice per week meat, whereas the luxurious food package is similar

Table 2. Action perspectives for sustainable development of the world food supply. (Source: WRR, 1995).

	Luxurious package	Moderate package
Globally-oriented agriculture	Utilizing	Saving
Locally-oriented agriculture	Managing	Preserving

to that of the average Italian, and in the production sphere between a so-called *globally-oriented agriculture* and on a *locally-oriented agriculture.*

The globally-oriented agriculture aims at a combination of productivity and efficiency, making maximal use of the biological mechanisms that dictate the functioning of these agricultural systems. This agriculture does not exclude particular inputs such as fertilizers and biocides, but maximizes their efficiency and effectivity. The possibility to re-use these inputs are considered at the higher integration levels. The eco-technological insights that are made operational in such an agriculture requires much ecological literacy at all levels, from farmer to policy-maker, from grower to agri-businessmen. This ecological literacy comprises the best of all knowledge from Integrated Pest Management, Integrated Nutrient Management and Precision Agriculture.

The locally-oriented agriculture is based on the concept that all cycles should be closed at the lowest level. That implies a re-use of all resources at the lowest level and excludes the use of particular inputs as much as possible, such as artificial fertilizers and pesticides.

On a world scale an adequate food supply appears realizable for all four scenarios; depending on the scenario between 11 and 44 billion people can be fed. Regionally, self-sufficiency is not universally attainable; in East and Southeast Asia this is possible only given a moderate food package and globally-oriented agriculture. In Africa, enough can be produced for self-sufficiency under all four scenarios. This contrasts dramatically with the situation in the reference scenario.

These scenarios studies help to gain insight in how sustainability may be made an operational concept, they also help to show that perspectives are there, but require a considerable effort of the world community, globally and at a regional level. Extensive information on the scenarios, their results and political implications is given in the report 'Sustained risks, a lasting phenomenon' (WRR, 1995).

Farming systems research

The production technologies and the scenario studies are based on insight in and expertise of agricultural and farming systems. The globally-oriented agriculture is based on the best eco-technological insights and implies high productivity preferably at good soils and concomitantly reaching highly efficient utilization of physical inputs such as fertilizers and pesticides. Per unit of product this agricultural technique requires a minimum level of external inputs. Furthermore, comparatively little land is taken up at maximum/optimal levels of production. The further development of such eco-technologically advanced farming systems where all inputs can be used efficiently, land-use is optimized and negative side effects for the environment are minimized are described elsewhere in this volume.

In the locally-oriented agriculture, dependence on external inputs in general and more specifically fertilizers and pesticides are considered to be risky for the long-term continuity of these agricultural systems. The introduction of alien substances and the long-range transportation of potentially harmful substances (e.g. fertilizers and pesticides) are considered to pose an undue risk to the environment. It is for this reason that carbon and nutrients cycles should be closed as much as possible. This implies exclusion of specific external inputs. Especially here mixed farming systems that combine animal and plant production may be considered as a way to reach the ultimate objectives in the best possible manner.

The risk perception and the normative constraints which are accepted in the two farming systems are different, their dependence on external inputs varies, but the way they are developed is similar. It is clearly the intention to reach optimal systems that answer best the different objectives. Efficiency, efficacy and productivity are the major aims of the globally-oriented agriculture system, whereas the locally-oriented agriculture has as major aims: (*i*) independence of particular external inputs, (*ii*) well-being of animals, and (*iii*) closed loops of nutrients and carbon at farm level.

The possibilities for various farming systems and their viability may vary at different places around the world. In places where population size, population density per km^2 and the ratio arable land/rangeland is high (in rangelands the natural fertility is accumulated with cattle, and the manure is used on the arable land), the possibilities for locally-oriented agriculture are very limited, whereas in situations where these parameters are low, the possibilities are much higher. That explains the ample opportunities for locally-oriented agriculture in relatively sparsely-populated Europe, and the absence of such possibilities at the highly-populated areas in East Asia, such as China.

Through the further development of various farming systems in an interactive manner with scientists and end-users further optimization of globally- and locally-oriented farming systems may be achieved. In this volume, various elaborations of such agricultural systems are given, with specific reference to mixed farming systems. This may help to gain insight in the research agenda of the future on the one hand, and the way various problems that well affect such farming systems are addressed on the other.

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Mixed farming as a way to sustainability

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Introduction

We are searching for farming systems that support sustainable development of land use. Farming systems are considered to be sustainable if natural resources, essential for agricultural production, are conditioned in such a way that future generations have the same opportunities for production as the present generation has. Sustainability is not something absolute. It has a lot to do with what present generations want to leave for future generations (WRR, 1995). So, the present generation is entitled to redesign current farming systems.

Main streams in agricultural thinking are very matter oriented. Social and management oriented aspects play hardly any role. More efficient farming systems, better-controlled production, effective varieties and chemical technology raised fantastic results. However, side effects, not noticed at the level of test plots in classic agriculture, scaled up as well. In my view, each thought in classical experimental agricultural research is afflicted with mistakes. Mistakes should be reduced by trouble shooting, further problem analysis and on-going experiments later on. So, agriculture, striving for sustainability, tends to make current farming more and more perfect, however, without wandering about the question if basic principles behind current farming are the best ones for getting more sustainability in farm production.

Specialization in current farming

In search for sustainability, agricultural research became very disciplinary oriented. Thus, current farming in The Netherlands became specialized very much. Physiological and molecular approaches condition protein production in such a way that primary production can be steered accurately, without minimal negative effects for natural resources around production sites. So, primary production became almost synonymous with some disciplinary research at suborganism level. Examples:

- Agronomy got plant physiological characteristics.
- Arable production became synonymous with soil fertility research and crop protection.
- Bulb production became synonymous with fytopathology and nematology.
- Fruit and tree production became synonymous with tissue propagation and breeding.
- Horticulture under glass became informatics and physiology.
- Flower production is synonymous with tissue propagation, breeding and crop protection.
- Animal production is like nutrition and technology.

All specialization in farming has one and the same phenomenon in common. They try to get better understanding of natural laws behind all performances of life. That approach of life removes all differences between biotic and abiotic phenomena at the long-term. At DNA level, there is no difference between a carrot and a cabbage, or between a cow and a human being. However, at higher levels of integration, differences are obvious. Classical approaches of farming, resulting in highly specialized agro-ecosystems, tend to smooth all biotic and abiotic differences at field level. Even precision farming, although a very smart kind of farming, tend to smooth all differences at the farm on a long-term, because biotic and abiotic variation seems not to be recognized as a natural resource for sustaining ecological cohesion at farm level.

Problem statement concerning mixed farming

In my opinion, further specialization in farming is risky, because

- Self-regulation and self-cleaning capacities of natural and environmental systems decrease irreversibly.
- Opportunities for flexible adaptation of farm management and farm system development in line with social demands, decrease step by step.
- Farmers become more and more dependent on governmental regulations.
- Farm management as a tool for getting more sustainability in farm production, becomes redundant.
- Freedom in choices for consumers becomes limited.

The question by now is: how to overcome further walking into a blind alley?

Strategy towards mixed farms

Each production system always converge (inputs result in end products). However, divergence occurs too: production of by-products (waste and emissions), which are considered mostly unusable. The more specialized a farm, the greater the number of unusable side products. For instance, for dairy farmers, manure is not a product but a waste. Thinking in cycles implies thinking in terms of input/output relations within processes at the farm itself. In mixed farms, such as an integrated arable and milk production farm, by-products become intermediate products. Such products become inputs for other farm processes or for rehabilitation of natural resources. For a mixed farm, natural resources become an essential part of the system. For a specialized farm, such natural resources are present as well, although they are not within the scope of farm management and farming system. Main streams in sustainable thinking concern management of cycles of matter at farms or between farms. Most important cycles concerned are:

- Nutrient cycles;
- Soil life;
- Water balances;
- Life cycles of certain key species;
- Producer/consumer cycles.

A key strategy in designing sustainable farming systems is to restore cycles as mentioned before. Any concept of a mixed farming system must include at least the following

(Spedding, 1975):
- Purpose: why is the system established?
- Boundary: where the system begins and ends?
- Context: the external environment in which the system operates.
- Components: the main constituents that form the system.
- Interactions: relationships among components.
- Inputs: items used by the system that come from outside.
- Product of performance: the primary desired outputs.
- By-products: useful but incidental outputs.

When envisioning a mixed farming system, it is important to consider following ideas (Altieri, 1995):
- A mixed farm is a collection of abiotic and biotic components, linked to form an ecological cohesive network.
- Self-organization and self-regulation are essential aspects of the system.
- A mixed farm is a product-flow system; by-products must become inputs for other farm processes (including restoration of natural resources) (Wolfert *et al.*, 1997).
- Mixed farming systems vary according to the nature of their components, assemblage in time and space, and level of human management.
- Mixed agro-ecosystems can be of any bio-geographical scale.

Designing
For the actual designing of a mixed farming system, it is important to understand that two fundamental ecosystem functions must be enhanced in agricultural production fields: biodiversity of micro-organisms, plants and animals on the one hand and biologically mediated recycling of nutrients from organic matter on the other. From a management viewpoint, the basis components of a mixed agro-ecosystem, that will enhance those functions, are (Vandermeer, 1998):
- Vegetative cover as an effective soil- and water-conserving measure, met through the use of adapted practices, mulch farming, use of cover-crops.
- Regular supply of organic matter through regular addition of organic matter and promotion of soil biotic activity.
- Nutrient recycling mechanisms through the use of crop rotations, mixed systems, agroforestry and intercropping systems based on legumes.
- Pest regulation should be done in a non-chemical or integrated way: agronomically, applied allelopathy, biological control and crop rotation.

Current research concerning sustainable mixed farming
At the Ir. A.P. Minderhoudhoeve, the experimental farm of the Wageningen Agricultural University, two mixed farms are laid out. On 135 ha a mixed farm 'according to best technological means' and on 90 ha a mixed farm 'according to best ecological means' have been developed. A reasonable size of both farms is essential, because preceding research indicated that smaller farm sizes reduced benefits of scale for mixed farms, quickly

(Lantinga & Van Laar, 1997). Both farms combine arable crops together with vegetables, dairy cattle and sheep. For the future, chicken and pigs might be included. Main objective is development of sustainable mixed farming systems, instead of reproducible research over many years or comparison between farming systems. At both farms, minimal emissions of matter are strived for. For the ecological farm there is an extra objective, namely minimal emission per ha and minimal dependency from external artificial inputs. Besides technology, also ethical implications of husbandry are taken into account. Housing of cattle and management of crops and farming systems might show that.

Mixed and sustainable farms are much more complex and decision-making is, therefore, not easy. Facilitating decision-making, research is done on electronic support of decision-making by the farmer himself (Wolfert, 1998). A model is in preparation. This model is based on 'enterprise resource planning', taken from process industry. Difference between this model and that of industry is that farmers don't deal with manmade machines and dead processes, but with ecological phenomena and living entities, which have their own autonomous regulation. That makes them less controllable. The model is, therefore, not the result of careful system decomposition, but a heuristic one.

Conclusions

Sustainable development of agriculture might be served by two approaches:

- Ongoing specialization of farm production (a development in depth).
- Despecialization by integration of production systems (a horizontal development).

The approach first mentioned, is technologically-driven and substitutes the farmer by scientists, industry and extensionists. Last mentioned approach is technologically- as well ecologically- and farmer-driven. Cooperation between farmers should then be enhanced.

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REGIONAL PERSPECTIVES FOR MIXED FARMING

Mixing specialized farming systems in Flevoland

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Introduction

Farming systems are subject to two opposed forces: differentiating forces and integrating forces (Van Niejenhuis & Renkema, 1996; Schmitt, 1985). Differentiating forces (e.g. cost savings related to mass production) stimulate farming systems to specialize, leaving few or even only one cropping or livestock system(s) at the farm. Integrating forces (e.g. the need to maintain soil fertility), on the other hand, lead to farming systems in which several cropping and/or livestock systems are combined. The impact of both opposed forces in the past has led to mixed farms, but since the 1950s, through improved technologies, differentiating forces became dominant, leading to a rapid specialization of Dutch agriculture. However, during the last decade a new integrating force became prominent (Van Niejenhuis & Renkema, 1996): the need to improve sustainability in Dutch agriculture. This could be achieved by re-introduction of mixed farming systems, that might result in (Lantinga & Rabbinge, 1996):

- Higher nutrient use efficiency (defined as the proportion of imported nutrients exported from the farming system in farm products);
- Reduction in the use of external inputs (fertilizers, biocides, concentrates);
- More efficient utilization of available labour.

Most important mechanisms underlying these expected benefits are use of home-grown concentrates, more efficient application of animal manure and wider crop rotations, including grass and feed crops.

Mixed farming systems can exist at different hierarchical levels. A mixed farming system at farm level comprises a group of farms each producing both animal and arable products. However, these mixed farms have disadvantages: they are more difficult to manage, require higher investments (Aarts, 1992) and provide less opportunities to take advantage of scale effects, explaining their strongly decreased number in the Netherlands. At regional level, a mixed farming system comprises at least two or more specialized farms, each producing crop or animal products, in which decisions are made, on the basis of goals and constraints of both farms. In mixed farming systems at regional level, the economic benefits of specialization at farm level and environmental benefits of integrating cropping and livestock systems at regional level are combined (Van Niejenhuis & Renkema, 1996). Therefore, they deserve further attention.

This paper compares agronomic, environmental and socio-economic characteristics of two specialized farming systems with those of one mixed farming system at regional level. The two specialized systems are defined as a specialized arable farm and a specialized dairy farm, respectively. The mixed farming system is defined by the same two, intensively co-operating specialized farms, exchanging land, labour and machinery. For all three farming systems nutrient balances, labour utilization and labour income are quantified. Scope for reduced biocide use in the mixed farming system is assessed in a qualitative way. To guarantee that only effects of mixing specialized farming systems are quantified (and not effects of, for example, different farming intensity or scale effects), the following conditions are imposed: (*i*) crop areas and milk production per ha grassland and fodder crops in the mixed farming system are equal to that on its component parts, (*ii*) the amount of forage purchased in the mixed farming system should not exceed the amount purchased on the specialized dairy farm, and (*iii*) within the mixed farming system the machinery of the arable and dairy farm is combined.

Methodology

General

In this study, many data are fixed (crop areas, machinery). Therefore, relatively straightforward calculations suffice. Calculations have been based on a normative approach, departing from current agricultural practices. Specific year effects are avoided by using multi-year averages for crop yields and animal production. Data used apply to the physical environment in southern and eastern Flevoland. The soil is a calcareous marine loam soil (clay fraction 25-35%, pH-KCl 7.3-7.6, organic matter content 3-6%), reclaimed from the sea 40 years ago. During the growing period, depth of the groundwater table is *ca* 1.5 m.

To assess the impact of mixing specialized farming systems on nutrient use efficiency, a nutrient balance approach is applied, considering nitrogen (N) and phosphorus (P). All inputs are quantified, and those outputs leaving the farm gate in useful products. The difference between total inputs and outputs in useful products is either lost to the environment or stored in the soil reserves.

Labour requirements are calculated for each half-month period of the year for each of the three farming systems, using normative task times (Anon., 1994, 1995). Annual labour availability amounts to 2093 hours per full time labourer on the arable farm (Anon., 1994) and 2349 hours per full time labourer on the dairy farm (Anon., 1995). A maximum labour availability per period was assigned to each period of the year following De Koeijer & Wossink (1992) for the arable farm and according to Van Mensvoort (1993) for the dairy farm. For the mixed farming system, labour availabilities and labour requirements per period per farm were added. By confronting labour requirements and labour availability per period, the need for hiring external labour was assessed.

Labour income was calculated as revenues minus fixed costs (buildings, machinery, land) and variable costs (costs of external inputs, contract labour, hired labour, etc.). Data to calculate revenues and fixed and variable costs are given in Anon. (1994) and Anon. (1995).

Scope for reduced herbicide use in the mixed farming system has been assessed by

Table 1. Characteristics of the farming systems.

	Arable farm	Dairy farm	Mixed farm
Size	80 ha	72 ha	152 ha
Crop areas (ha) and rotations	- sugar beet (20 ha); winter wheat (20 ha); seed onions (10 ha); grass seed (10 ha); ware potatoes (20 ha)	- ley (4×10 ha); maize (2×10 ha) - permanent grassland (12 ha)	- onions (10 ha); ley (1-4 years old, 4×10 ha); ware potatoes (10 ha); winter wheat (10 ha); sugar beet (10 ha); maize (10 ha); ware potatoes (10 ha); grass seed (10 ha); winter wheat (10 ha); maize (10 ha); sugar beet (10 ha) - Permanent grassland (12 ha)
Milk production per ha grassland and fodder crops (kg FPCM* yr^{-1})	-	16352	16352
Manure management	Application of pig slurry on catch crops in late summer after early-harvested crops	Application of cattle slurry on grassland in growing season	Maximum application of slurry on leys in growing season, the remaining on catch crops after early-harvested crops
Full time labourers present	1	2	3
Contract labour	Sowing and harvest of sugar beet and grass seed; sowing onions; harvest of wheat; application of slurry	Cultivation of maize, soil cultivation, resowing grassland, application of slurry, maintenance of ditches	Sowing and harvest of sugar beet, grass seed and maize, sowing onions, harvest of winter wheat, manure application, maintenance of ditches

* FPCM = Fat and Protein Corrected Milk (4% fat; 3.4% protein)

comparing crop rotations in the specialized farming systems and the mixed farming system with respect to weed-suppressing capacity. Scope for reduced pesticide use is assessed by examining: (1) against which pests and diseases biocides are applied in the specialized farming systems, and (2) whether the occurrence of these pests and diseases will be reduced in the mixed farming system.

Based on data provided by the Dutch Central Bureau of Statistics and the Dutch Cattle Syndicate, a representative arable and dairy farm have been defined. Definition of the three farming systems is summarized below. See Bos (1998) for details. Important characteristics of the farming systems are given in Table 1.

Arable farm

The nutrient balance of the arable farm was calculated using a target-oriented approach. First, total nutrient removal in crop products is calculated. Subsequently, the required amount of nutrient inputs to realize this nutrient removal is calculated. P-requirements of the whole crop rotation are met using pig slurry. Annual P-input with pig slurry should equal P-removal in crop products plus 9 kg P ha^{-1} yr^{-1}, the P-surplus allowed by the Dutch government. To prevent soil structure damage, slurry at arable farms is applied in late summer, after early-harvested crops. Application of pig slurry is followed by a catch crop. Sources of N are soil mineral N present in spring, mineral N originating from decomposition of soil organic matter during the growing season, N from crop residues, N in pig slurry and, if required to meet crop demands, N in artificial fertilizer.

After application of pig slurry in late summer combined with a catch crop, 35% of total N applied with slurry is assumed to be available for the next main crop (Schröder *et al.*, 1996). The remainder is assumed to be either emitted to the environment, or stored in the soil reserves.

Dairy farm

Maize rotates with 40 ha of the grassland area, leaving 12 ha permanent grassland. Each year, 10 ha of ley is ploughed up, followed by maize for two successive years. Grass dry matter yield is derived from the empirical relationships between (*i*) N-availability and N-uptake and (*ii*) N-uptake and dry matter yield (Middelkoop & Aarts, 1991). N-application rate on grassland is set to the economic optimum of 400 kg ha^{-1} yr^{-1} (Prins, 1983). Farm-produced cattle slurry is evenly distributed over the total grassland area and applied in three doses, the last one after the second cut.

Herbage quality, animal feed requirements and feed intake are calculated using routines from a dairy farming model (Van de Ven, 1996). By confronting total feed intake of the animal stock with on-farm roughage production, the need for purchased feed is assessed.

Maize receives artificial N fertilizer only, for which the required dose is assessed, following the same procedure as applied to the arable farm, however taking into account nitrogen released in the first and second year after ploughing up grassland. P-requirements of maize are met with cattle slurry applied to grassland.

Mixed farming system

A wider crop rotation may be established by incorporating the total maize area and the maximum grassland area from the dairy farm into the crop rotation of the arable farm. On the specialized dairy farm, 12 ha is permanent grassland. Consequently, 40 ha of grassland can be incorporated into the rotation as leys, that are ploughed up in November after their fourth summer. Each year 10 ha of ley is sown after an early-harvested crop and 10 ha is ploughed up. As on the specialized arable farm, P-requirements of the whole crop rotation are met using slurry, however, cattle slurry is added to the pig slurry. On the specialized arable farm, pig slurry has to be applied in late summer, resulting in a low N utilization efficiency. In the mixed farming system, part of this slurry can be applied in the growing season on grassland. Application of slurry in late summer can thus be avoided by maximizing slurry application on grassland. This slurry application strategy is aimed at accumulating P in the soil profile under grassland such that P-requirements of crops grown after ploughing up grassland, are met as much as possible. The maximum dose per cut is set at 30 m^3, while per year a maximum of three doses can be applied, the last dose after the second cut. The cropping frequency in the specialized farming systems is higher than in the mixed farming system, which results in yield reductions for some crops in the specialized farming systems, due to soil-borne pests and diseases (Habekotté, 1994). Within the mixed farming system, these yield reductions do not apply. It is assumed that the higher-yielding crops in the mixed farming system have the same nutrient concentrations as in the specialized farming systems and that nutrients are taken up with the same (crop-specific) efficiencies.

In the mixed farming system, the machinery of both specialized farms is combined. As a result, the mixed system is less dependent on contract labour, provided available labour is not yet fully utilized. Contract labour is still used for activities for which the required machinery is lacking on both specialized farms.

Results and discussion

Nutrient balances

Nutrient balances of the specialized farming systems and the mixed farming system are given in Table 2. Differences between the combined nutrient balance of both specialized farming systems and that of the mixed farming system are small. Roughage input is lower in the mixed farming system because of a higher maize yield, reducing the need to purchase maize. Nutrient output is somewhat higher in the mixed farming system, because of higher yields for sugar beets and ware potatoes. As crop nutrient requirements were calculated using a target-oriented approach, a higher nutrient output with crops in the mixed system requires higher inputs, explaining the somewhat higher pig slurry input. Higher N use efficiency was to be expected in the mixed farming system, because pig slurry can be

Table 2. Nutrient balances of the specialized farming systems and the mixed farming system, all expressed in kg ha^{-1} yr^{-1}.

Area	Arable farm 80 ha		Dairy farm 72 ha		Total specialized 152 ha		Mixed 152 ha	
	N	P	N	P	N	P	N	P
Inputs								
Pig slurry	147	37	0	0	78	20	81	21
Art. fertilizer	85	0	161	1	121	0	126	0
Roughage	0	0	46	7	22	3	20	3
Sundries	34	0	138	25	83	12	83	12
Total inputs	266	37	345	33	304	35	310	36
Outputs								
Crop products	145	29	0	0	77	15	82	16
Milk/meat	0	0	102	19	48	9	48	9
Total outputs	145	29	102	19	125	24	131	25
Surplus	121	8	243	14	179	11	179	11

Table 3. Labour requirements and supply in the specialized farming systems and the mixed farming system, expressed in h yr^{-1}.

	Arable farm	Dairy farm	Total specialized	Mixed
Labour availability farmer(s)	2093	4698	6791	6791
Total labour requirements	2639	4740	7379	7436
On-farm labour input	1987	4424	6411	6585
Hired labour input (excl. contract labour)	652	316	968	851
Non-utilizable available labour	106	274	380	206

applied on grassland in the growing season, instead of application in late summer. However, due to the ratio between grassland and arable crops and the relatively high cattle slurry production per ha of grass (related to the intensity of the dairy farm), the amount of pig slurry that can be applied on grassland is limited to only 15% of all pig slurry. Consequently, N use efficiency is hardly improved.

Calculation of nutrient balances can be characterized as crude: soil organic matter dynamics, strongly influencing N-flows in agro-ecosystems, have not been taken into account. Assuming equilibrium situations at farm level, soil organic matter levels can be expected to vary among the three farming systems, with the highest level occurring at the specialized dairy farm and the lowest level at the specialized arable farm. As a result, net mineralization rates will differ among the three farming systems. Different organic matter levels may also influence the efficiency with which crops utilize soil mineral N, because of different physical, biological and chemical properties of the soils. Both factors have not been taken into account in calculating nutrient balances.

Labour requirements

In Table 3, an overview is presented of the annual labour availability and requirements, the calculated on-farm labour input, the required hired labour and the non-utilizable labour (calculated as available labour minus on-farm labour input) in the three farming systems. It shows that the annually hired labour is 12% lower in the mixed farming system, due to substitution of hired labour by labour still available at the dairy farm part or the arable farm part.

Total labour requirements are higher in the mixed farming system, because contract labour is partly substituted by own labour: cultivation and ploughing of the maize stubble, seedbed preparation for leys to be established and ploughing up of grassland can in the mixed system be carried out with own labour and machinery, where in the specialized farming systems these activities have to be carried out using contract labour. Because of the higher on-farm labour input in the mixed farming system, non-utilizable labour is lower, or, in other words, available labour is used more efficiently.

Labour income

Labour income in the mixed farming system is about Dfl 500,- ha^{-1} higher than in the

Table 4. Costs, revenues and labour income in the specialized farming systems and the mixed farming system, all data in Dfl yr^{-1}.

	Arable farm		Dairy farm		Total specialized		Mixed	
	abs.	per ha	abs.	per ha	abs.	per ha	abs.	per ha
Fixed costs	259905	3249	435552	6049	695456	4575	695456	4575
Variable costs:								
Costs contract labour	43042	538	71099	987	114141	751	101699	669
Costs hired labour	17857	223	8659	120	26516	174	23338	154
Other variable costs	158502	1981	224940	3124	383441	2523	375780	2472
Total costs	479306	5991	740249	10281	1219555	8023	1196272	7870
Revenues	591409	7393	951285	13212	1542694	10149	1597411	10509
Labour income	112103	1401	211036	2931	323139	2126	401139	2639

specialized systems (Table 4). This higher labour income is mainly due to higher revenues, making up 70% of the increase in labour income, rather than to lower costs. Higher revenues in the mixed farming system result from higher yields per ha of the profitable crops sugar beets and ware potatoes.

Biocides

Crops differ in weed-suppressing capacity. Weeds can thus be suppressed by alternating crops with low weed-suppressing capacity with those with high weed-suppressing capacity (Vereijken *et al.*, 1994). In general, mown crops have a higher weed-suppressing capacity than root crops.

As the share of mown crops (grass) in the rotation in mixed farming system is higher than in the specialized arable farming system, in the longer term weed incidence in arable crops may be lower, reducing the need to apply herbicides. Empirical data supporting this are, however, lacking (Van Dijk *et al.*, 1996; Hoeksta & Lamers, 1993; Schotveld & Kloen, 1996). An explanation could be the absence of stimulation of seed germination through soil cultivation in grassland, leaving the seed bank intact, and the fact that seeds under an undisturbed grass sward remain viable many years (Van Dijk *et al.*, 1996).

The pesticides used in the specialized farming systems are all applied to control non-soil-borne pests and diseases like beetles, aphids, mildew and wire worms and for haulm killing (Anon., 1994, 1995). Consequently, in Flevoland widening of crop rotations is not likely to influence the need to apply pesticides.

Conclusions

In this paper it was shown that in a mixed farming system it is possible to gain a higher income without an increase in environmental pollution. In other words, assuming that in agricultural practice nutrients are not limiting production, it is possible to reduce environmental pollution of Dutch agriculture without income loss while maintaining production levels. In this respect, mixed farming systems seem promising. Key factors are the ratio between animal and arable production, determining the extent to which crop rotations can be widened and the relative amounts of slurry that can be applied on grassland. Moreover, various ways of mixing specialized farming systems are possible, e.g. involving other crops, animals and management options. Systematic model analysis, combining quantification of agro-ecological, environmental and socio-economic indicators for a wide range of production techniques and optimization, seems a promising approach to the exploration and design of mixed farming systems.

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Modern solutions for mixed systems in organic farming

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Introduction: the decline of the mixed farm

Over the last few centuries, mixed farm systems have developed throughout Europe, involving cattle farming, arable farming, fruit growing, horticulture, and, frequently, forestry. Those regions in the Netherlands in which the water-table was too high or the soil too heavy had to resort to specialized livestock farming, i.e., to dairy, beef and sheep farming. In other areas mixed farm types have been established, whose activities depended mainly upon their natural soil fertility.

Over the course of a millennium, the Dutch sandy regions for example, saw the development of systems of cultivation based on *es*-lands (arable land manured with turf and farmyard litter). Only the arable land was fertilized with natural sources (7.5% of the total surface area). In 1800, it was possible for one hectare of *es*-land to support two people and 0.3 horses. This required 9 hectares of heathland (on which 9 sheep grazed) and 2.1 hectares of meadowland and pasture (on which 1.7 cows grazed). The data calculated were per hectare of *es*-land for the inputs (of manure, hay and turves, excluding rainfall), and for outputs such as rye (at a yield of 1.1 t ha^{-1}) (Table 1, De Smidt, 1979). It can be seen that in case of phosphate the input and output (exclusive of losses) was almost in equilibrium. Due to soil exhaustion and deficiency diseases, this farming system collapsed. Yields improved again after 1865, due to the use of phosphate fertilizers. The use of imported fertilizers (such as guano and Chilean nitrate) meant that, by 1920, the last flocks of sheep had disappeared from the province (Edelman, 1974).

The introduction of fertilizers at the end of the nineteenth century is probably the most radical change ever to have taken place in agriculture, one that represented the first impulse towards the segregation of farming activities, and thus towards specialization. In The Netherlands, after World War Two, especially the introduction of nitrogen fertilizer led to further intensification and to the complete segregation of all branches of farming. The huge surface area of farmland outside The Netherlands (and the concomitant international trade in grain, soya, tapioca, etc.) now means that less and less Dutch agriculture is land-related, i.e., that the ratio of animals per hectare is severely out of equilibrium.

Table 1. Input and output of minerals per ha of arable land, around 1800 (*es*-cultivation).

	N	P_2O_5	K_2O	Ca	Mg
Input ha^{-1}	31	14	31	25	12
Output ha^{-1}	22	11	8	3	2

Hence, in the years before 1850, all farms needed a mineral source to maintain the system. In the sandy districts, this source was the large area of heather, which, year by year, gradually became impoverished. In the clay soil areas, it was either the frequent flooding with clay minerals, or the release of minerals from the subsoil (i.e., the ripening of clay); in the fen area it was a result of peat shrinkage, which led to mineralization. As time went on, more frequent recourse was taken to urban nightsoil and other refuse, thus closing the cycle of minerals from the towns. Soil type, moisture and basic soil fertility (i.e., that of sand against that of clay or peat) determined not only the standard of living, but also the farm breeds, including the so-called land races.

The development of organic agriculture

Organic farm practices in any country reflect the practices in conventional farming in that land, a fact that explains the intensive and highly specialized nature of Dutch organic agriculture. This specialization has been possible thanks to the flexible norms for organic farming, particularly with regard to manure inputs and the external cultivation of roughage and concentrates. The regulations lay greater stress on organic produce than on the organic farming system – for example, by banning biocides and not using fertilizers. In the dairy sector, the expansion allowed by these norms has created farms on which milk production approaches 15,000 kg ha^{-1}, without virtually grazing, and where an area of up to 80% of a farm's own area is necessary for the cultivation of feed crops (Baars & Van Ham, 1996).

In arable farming, too, there is currently a move towards high-profit crops grown in short (i.e., 3- to 4-year) rotations, without any place for such soil-improving crops as grass-clover mixture or grain. All compensation for mineral offtake, loss of organic soil matter and soil-structure improvement takes place in the form of manure inputs derived from the manure surplus from conventional agriculture. In this way, another part of the area of arable farms is also external.

By contrast, there are also farms that adhere to the archetype of farms that are not only mixed, but also versatile and self-sufficient, and virtually closed in terms of mineral inputs. The mineral balances of such farms usually show a negative balance with respect to potash and phosphate, thus indicating that the natural weathering of the soil is being exploited, or that soil exhaustion will follow in the long-term. The consequences of such practices are that low yields have to be accepted. One example of such a closed farm system was the former mixed bio-dynamic experimental farm in Nagele (1976-1985). Here, the only external input consisted of heathland litter (Table 2). In 1985, this farm transformed to the principle of balance-establishment, especially with regard to phosphate (i.e., the purchase of concentrates and of straw) (Baars, 1991).

Eventually, this bio-dynamic farm was also segregated, since when it has been run as an arable farm also growing large field vegetables. Manure is derived from external sources.

Farm collaboration

Segregation is now a fact of life in Dutch organic farming. While this promotes the development of specialist skills, the specialization of people should not lead by default to the

Table 2. Mineral balances of the experimental mixed bio-dynamic farm at Nagele (North East Polder, The Netherlands), before (1984-85) and after (1986-88) balancing phosphate input and output.

	1984-1985			1986-1988		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Inputs (bought):						
Concentrates	-	-	-	50	42	72
Straw	8	1	1	20	16	22
Deposition	45	5	22	45	5	22
N_2-fixation	100	-	-	100	-	-
Total input	153	6	23	215	63	115
Outputs (sold)						
Plant products	27	15	22	35	37	58
Animal products	22	21	12	25	26	7
Total output	49	36	34	60	63	65
Input - output	104	−30	−11	155	0	50

specialization of farms. One solution might be for a number of specialists to collaborate within one large mixed farm, another for a form of regionally-based collaboration between independent, specialized farms – amounting, in effect, to mixed farming-at-a-distance.

A study by the Louis Bolk Institute (Van Rijs, 1996) of existing collaboration among organic farms demonstrates the opposing interests of arable farmers and livestock farmers. Arable practice focuses on the provision of organic matter (for the purposes of soil structure), nitrogen (for production) and minerals (for the mineral balance). Livestock farmers are interested in supplementary feedstuffs (with regard to their feed-status) and straw (for litter). They are also of the opinion that they need the manure for their grassland, and that there is no manure surplus on their farms – especially not on the more extensive farms (i.e., those with one dairy cow ha^{-1}, or fewer).

A number of reasons, therefore, hinder collaboration between arable and livestock farmers:

- It is difficult to establish the values of the products that are to be exchanged or sold: for example, there are differences between assessments based on financial criteria (i.e., costs), and those based on land area, dry matter production and soil organic matter.
- Organic manure is assessed at a low economic value, as conventional manure is regarded as a waste product.
- Insufficient quantities of manure are available; this is due partly to the type of crop rotation practised on arable farms and in market gardening, and partly to the fact that livestock farmers need (or believe they need) their manure for the supply of phosphate and potash.
- Insufficient straw is produced in current arable crop rotations. The area under cereals on arable farms is small (thereby leading to lower profit margins), but keeping animals inside also requires considerable quantities of straw (i.e., in deep litter houses).

- Cereals are currently grown for bread, not concentrates. For many growers who believe that a cow should convert roughage that is indigestible for humans, this is a point of principle.
- There is a considerable price differential between cereals for bread and those for fodder. The cereal crops, on which profit margins are already low, come under further economic pressure when grain is sold for concentrates.
- The profit margins on grass-clover mixture, fodder silage maize, fodder beet, and peas and beans for animal consumption are low, sometimes too low, compared to those of commercial crops. This makes it unattractive to grow feed crops, including leguminous crops, especially when land prices are high.

These problems cannot be seen in isolation, since in both farm types the use of leguminous crops plays a crucial role in the search for solutions: these crops are the motor driving any organic system. Both, directly (i.e., in building up humus and nitrogen in the soil) and indirectly, a ration containing sufficient quantities of leguminous material will lead to farmyard manure with a higher nitrogen content.

The importance of legumes

In grassland, there is a direct correlation between white clover yield (X, t dry matter ha^{-1}) and total yield (Y, t dry matter ha^{-1}). A grass-clover mixture grown on young marine clay in an arable rotation (Van der Meer & Baan Hofman, 1989) showed the following correlation:

Grass-clover in rotation $Y = 2.76 + 1.47\ X$ ($r^2 = 0.85$; N = 20) (1)

Our own research on hydromorphic gley soils (with grass-clover mixture after grass) suggested that the correlation was dependent on the type of manuring:

Phosphate and potash only: $Y = 5.56 + 1.01\ X$ ($r^2 = 0.77$; N = 44) (2)

Farmyard manure (deep litter): $Y = 6.90 + 0.78\ X$ ($r^2 = 0.84$; N = 44) (3)

Shallow injection: $Y = 8.18 + 0.51\ X$ ($r^2 = 0.58$; N = 44) (4)

The regression lines show, that as the availability of nitrogen increases (due either to organic soil matter or to manuring), the effect of white clover on total yields diminishes. At high N-application rates it is even possible that the clover yield may exercise a negative effect on total yield. In an organic system, the leguminous crops can make the greatest contribution to production if the N-input is low, or even entirely absent. Absence of a leguminous crop in the mixture will lead to a significantly lower yield, particularly in nitrogen-poor soils (Eqn 1). As experienced with cvs. Retor and Huia, inappropriate species can greatly reduce grass-clover production. Some livestock farmers compensate for disappointing clover persistence – either when clover fails after a severe winter, or due to slug-damage in the growing season (Baars & Brands, 1996) – by increasing their manure applications (Eqn 4).

Next to a number of management factors (e.g., grazing type, autumn/winter grazing, stubble-height and the introduction of an additional silage cut), the conditions for good grass-clover production also depend on the choice of the appropriate clover variety, and on abiotic factors. Schwinning & Parsons (1996) have shown the effect of irrigation on clover. Besides, much research has also been conducted on the role of Ca, P and K on clover

Table 3. Effects of manure type and manure-application levels on total yield and white clover yield (1997), and on pH in spring 1998, (5 cuts per year).

Level	Total yield t dry matter ha^{-1}			White clover t dry matter ha^{-1}			pH (KCl) spring 1998 (0-5 cm)		
	P+K	ShI	FYM	P+K	ShI	FYM	P+K	ShI	FYM
1	10.0	11.7	11.7	5.7	5.7	5.1	4.9	5.4	5.4
2	10.7	11.8	12.5	6.2	4.6	6.2	4.7	5.1	5.6
3	11.6	12.4	12.3	7.1	4.6	5.5	4.5	5.3	5.8

Farmyard Manure (FYM) 1, 2 and 3, resp. 30, 40 and 50 t ha^{-1} yr^{-1},
Shallow Injection (ShI) 1, 2 and 3, resp. 30, 30+10 and 30+10+10 m^3 ha^{-1};
P+K 1, 2 and 3, resp. superphosphate (54, 81, 108 kg P_2O_5 ha^{-1}) + potash fertilizer (156, 234, 312 kg K_2O ha^{-1}.

development. Extended studies in the Netherlands (Elberse *et al.*, 1983), but particularly in England (Thurston *et al.*, 1976), have demonstrated the importance to leguminous plants of calcium, phosphate and potash, whether singly or in combination. And in grazed fields with grass-white clover, the growth of clover has been shown to react strongly to an increase in Ca, P and K (Fothergill *et al.*, 1996). Differences in productivity of organic grasslands in England display a close link between grassland production and soil P-value (Newton & Stopes, 1995).

When clover cover is good, manuring is usually carried out in organic livestock farming to maintain soil pH, P and K status. While an early slurry application causes crop production to shift towards growth earlier in spring, sufficient P and K status have little effect on total yield. This effect is shown clearly in our own study on the effects of increasing quantities of manure on grass-clover development. Grassland production in year 2 (1997) shows the tangible effects of higher phosphate/potash applications, both on the development of white clover and on total yields (Table 3). The disadvantage of the P/K application is the concomitant fall in soil pH (initial soil pH was 5.4).

Higher levels of P/K both led to higher total yields and to higher clover yields. In terms of yield, the highest level of P+K fertilization was comparable to the lowest levels of organic manure. However, the clover yield is much higher. In contrast with the yields produced by increased levels of manure application, lower clover yields result from higher applications of slurry (40 and 50 m^3 ha^{-1}).

Conclusions: solutions for farm collaboration

To bridge the gaps outlined above, it is important that both arable and livestock farmers should relearn a mixed-farm philosophy. In this, grass-clover is The Mother (Von Thaer), or The Central Bank of the organic farming system (Younie & Baars, 1996). It is important to livestock farms that milk be produced primarily on the basis of roughage. There are various examples of organic farms that produce 6,000 kg solely on this basis (Haiger, 1991;

Baars *et al.*, 1995). Cereals otherwise used as concentrates can then be used for human consumption. The current milk yield should fall rather than rise. Dairy cows should be kept not only for milk, but also for manure. To increase manure production, cattle farmers can keep a larger number of cows in the byre, each producing less milk. To enable the sale or exchange of manure, grass-clover production should be optimized by means of the following:

- Favourable basic soil fertility: i.e., a pH that is sufficiently high, with an appropriate potash and phosphate supply, i.e. supplementary use of fertilizers might be necessary;
- Favourable moisture supply, particularly in summer and on drought-sensitive soils;
- Frost and slug-resistant clover varieties.

On arable farms, too, adaptations are necessary to achieve collaboration among divergent farm systems:

- Cultivation of grasses and cereals through maintenance of organic matter content will improve soil structure, and reduce the need for manure. Cereal crops are necessary for the production of straw-rich manure.
- Cultivation of leguminous crops (both annuals and perennials) will reduce the need for manure-derived nitrogen.

Finally, it would benefit both systems, if work were done on closing the mineral cycle in society at large, i.e., with regard not only to urban compost, but also to nature areas. The history of agricultural systems dating from before the introduction of chemical fertilizers shows that the productivity of each system was determined by the level at which the various nutrients could be supplied. Each of these systems had a demonstrable source of nutrient supply. The higher production levels of modern farming systems (both organic and conventional) means that dependence on external nutrients has increased rather than fallen.

This means that when the world of organic farming believes it to be unethical to derive nutrient inputs from conventional agriculture (Baars & Van Ham, 1996), higher phosphate and potassium fertilizer inputs will be needed to replace them. This is a point of discussion within the sector, one that reopens the debate on whether or not fertilizers should be allowed within organic agriculture.

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Linking Environment And Farming (LEAF): Experiences of adopting Integrated Farm Management in practice on mixed LEAF Demonstration Farms

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Introduction

Like so many successful ideas, Integrated Farm Management (IFM) is simply common sense (Meerman *et al.*, 1992). It provides the basis for efficient production, that is economically viable and environmentally responsible, through integrating beneficial natural processes into modern farming practices to minimize external inputs, while conserving, enhancing and recreating that which is of environmental importance. This may be achieved by combining crop variety choice, selective use of pesticides and artificial fertilizers, together with controlled slurry and farmyard manure management, appropriate regard for animal welfare and improved energy efficiency, together with a positive management plan of landscape and wildlife features. All in all, placing the emphasis on attention to detail.

IFM does not set out a set of specific prescriptions. It does, however, identify a set of principles and procedures that have to be applied, taking account of the specific circumstances of the farm and its surroundings.

Integrated Farm Management (IFM) is principally an informed management approach. LEAF shows farmers that through IFM, they can realize optimum yields, produce wholesome food at reasonable cost *and* take effective measures to protect the environment, whilst maintaining profit (Aarts, 1996). Total quality and risk management is generally regarded as the key to success in the 1990s, it is for this very reason that LEAF was set up in 1991 as part of a pan European approach, the European Initiative for Integrated Farming, to actively promote IFM. Firstly through the setting up of demonstration farms throughout the UK (to date there are 26) and secondly through the development of the LEAF Audit, a self-assessment approach to direct farmers in the principles of IFM. LEAF encourages farmers to adopt IFM through visits to its national network of Demonstration Farms, allowing discussion, so farmers can take up practices relaxant to their farm.

Through these farms, LEAF is also raising awareness amongst non-farmers of how IFM is addressing their concerns. All these demonstration farmers are volunteers and host between 8-10 visits per year to invited visitors such as farmers, environmentalists, consumers, retailer groups, members of Parliament, etc.

Setting the scene

'It is my belief that the successful business of the 1990's will require a major change in attitude to the whole problem (of integrating production and environment) ... in fact I believe

... that the pursuit of better, more environmentally friendly methods of production will bring business rewards in their own right.'
These words of Sir John Harvey Jones, from his book 'Managing to survive' (1995, Fontana, London) refers to all businesses and it could not be more true for farming. Furthermore, it is an area that agriculture has been addressing for many years, but we have not been too successful at conveying it to our customers. Traceability, standard quality assurance, BS7750, ISO 9002, the Farm Assured Quality standards, all conjure up pictures of professionalism. Again, these are all words we would like to think are associated with the farming industry and ones that we are more likely to use in the future as products and processes become increasingly accountable throughout the food chain. Furthermore, this area of accountability is consistent with the aims of LEAF.

IFM - Integrated Farm Management

IFM has been termed as evolution rather than revolution. It is a combination of farming practices which balance the economic production of crops, through the application of rotations, appropriate cultivation measures, choice of seed variety, judicious use of fertilizers and pesticides, positive animal welfare, record keeping, energy efficiency, etc., with measures which preserve and protect the environment. IFM is a whole farm approach that is site-specific and based on understanding of the biological and ecological interactions, in nutrient cycles, pests, weeds and diseases of crops and the integration of livestock, their management, health and welfare, with farm management systems. It is also geared towards sustaining and optimizing the utilization of natural resources, such as a farmyard manures and slurries and the inclusion of legumes and green manures into the cropping system where practical.

It is not a new concept, but is built around existing knowledge and sound husbandry practices. However, while many of the practices are not new, they are dynamic and need to be regularly updated to include the results of current research and new technologies.

Since agriculture is dependent on many variables, such as climate, topography, site and markets, it is not possible to adopt a blueprint for farming, instead it is necessary to examine the best options for each individual site. This includes regular soil testing, accuracy of applications, timing, regular calibration and maintenance of machinery, etc. It also looks at the selection of machinery to match crop and soil type and addresses the environment policies of suppliers to the farm as well as those that carry out work on the business.

IFM takes into account the whole farm, and where there are livestock on the farm, their welfare and management, the use of slurries and farmyard manures and their contribution in the nutrient balance and inorganic fertilizer applications to reduce the risk of leaching, the use of medication and health and safety aspects, etc., are all fundamental to the system.

As the long-term viability of any farm business is the key to its success, it is essential that the management system that is adopted looks at both the economic and environmental viability of the business. Sound environmental management is not only the maintenance and stimulation of wildlife and habitats, it is also the management of soil, air and water. It is the positive management of these factors that results in a better use of resources and consequently a reduction in waste, and less risk of pollution.

For livestock systems, the mobility of stock in the system, the daily feeding, health considerations, breeding operations, seasonal feed and forage sources, all add to the complexity of any system. Therefore, successful farm management plans should include enterprise calendars of operations, stock flows, forage flows, labour needs, herd production records and land-use plans. Grassland management and that of any forage crop, such as maize, fodder beet, etc. should be in such a way as to take into account the soil, its compaction and erosion.

As for the implementation of any system, it is essential that it can be implemented practically, with good common sense so that good housekeeping leads to management practices that optimize the use of inputs. Technology is becoming more and more refined and we are able to assess the impact of farming decisions on the environment with increasing precision. IFM combines these practices as a responsible mix of best modern technology integrated with the best of traditional methods.

Integrated Farm Management - in practice

Whilst much of the work on LEAF has been concentrated in the arable sector, it is evident that where livestock are part of the farm the benefits of adopting a fully integrated approach are substantial. To follow are some of the key findings of three such farms.

Integrated Farm Management - a viable option?

Firstly, we will take a farm where a case study was carried out looking at the economic impact of the adoption of IFM.

The development plan was based on a typical dairy/arable farm in the heart of the dairy country on a medium light loam soil. The tenant farm runs 100 hectares of cropped land with a further 4 hectares of mature woodland. It included a principal rotation of winter wheat, winter oats, potatoes (rented out), grassland and 80 milkers run as a 'flying herd' with a 20% replacement rate.

The level of production from the herd was limited by quota and the farmer's personal choice of not wishing to invest in a higher quota. The case development plan investigated the projection of what could happen with the changes required to adopt a more integrated approach on a dairy/arable farm.

In the development of more integrated practices at the farm, several assumptions and specific practices were accounted for and included:

- Inputs more targeted through: better spreader calibration, improving the placement of fertilizer; regular soil and tissue testing for trace elements and fertilizer rates adjusted for slurry and farm yard manure applications.
- Investment in a combination drill to increase timeliness of drilling with a view to contract out at a later date.
- Introduction of maize into the rotation. A mixed forage diet increases the overall efficiency of digestion of the forage and concentrate intake.
- Taking back in hand the rented land since total control of inputs allows better land

utilization.
- Improved level of management and crop walking to ensure level and timeliness of inputs matched to crop requirements.

The results of the study showed that the targeted use of slurry on the maize ground reduced the inorganic fertilizer requirement and the overall use of fertilizer by 11%, whilst the biocide input increased due to the inclusion of maize. Furthermore, there was a slight increase in management input resulting from an increase in fixed costs. However, the overall findings, even with these additional costs, and some expenditures on conservation measures showed IFM to result in an increase in profit of 3.5%. An important point in terms of ensuring farmers of the economic viability of such an approach is that, through better attention for detail and focusing on resources, the impact of farming practices on the environment can also be reduced.

LEAF, focusing our thinking

A second example was from a family partnership on a 254 hectare mixed arable, dairy, pig and beef farm. The key issue on this mixed farm was that IFM offered a combination of responsible farming practices balanced by economically viable production techniques with measures to protect the environment.

The main impact of LEAF on this farm focused their thinking. Although they were meeting many of the IFM principles, they did not consider the different components as a whole package. Based on the LEAF Audit they now consider a wide range of factors that influence their farming in a disciplined way. In the past, they considered management on an enterprise basis rather than as part of the whole farm, which they now consider as the professional way to manage and plan their business.

Perhaps more surprisingly, the involvement with LEAF was also a great motivator for both the owner and the staff. The staff was always very keen to ensure a high standard of workmanship and involvement in the farm and hear what visitors had to say about the farm and appreciated the compliments and confidence of knowing that they were getting it right somewhere along the line. When showing visitors around the farm they found that they tended to be very conscious of the environment and activities of the farm, making them realize that they were not quite 100% perfect and this has been further used to improve farm performance (see also Aarts, 1996).

Additionally, the LEAF Audit was very helpful in bringing to their attention the areas of the farm activities that they might have been overlooking in terms of IFM, environmental protection and landscape development. The two hours spent carrying out the audit, focused the mind on many aspects of the farm and helped draw up an action plan for future targets and improvements.

Finally, the farmers considered that the exchange of information from LEAF and other bodies to the LEAF Demonstration Farmer and members was very important. Most problems are better solved by many people trying to think of a solution and then sorting through to find the best approach.

A case study looking at the economic sustainability of IFM was also carried out on this farm and again, even during one of the most difficult years for UK farmers, IFM showed substantial benefits, with an increase of 4% in the profitability of the system, in addition to the improved awareness and performance in environmental criteria and animal welfare.

Integrated Farm Management in the North

The final example refers to the experience on one of the LEAF Demonstration Farms in Scotland. Here, there were two distinct aspects to the farm's 401 ha (991 acres): the rolling farmland which grows arable crops, and the higher ground, rising to 180 m (550 ft), which fell into a Less Favoured Area and was best suited to grazing by the suckler cow herd in the summer months.

Although most of the grassland on the farm was permanent, the attention to detail required in IFM was equally applicable, with regard to stocking densities, nutrient management and avoidance of compaction, especially in the Less Favoured Areas.

Cultivation choice on the sandy loam and clay loam soils of the lowland areas were relatively easy to work as long as they were dry enough. After ploughing, to incorporate previous crop residues, good timing of subsequent operations was needed, to get autumn-sown crops sown as quickly as possible before weather conditions deteriorated. The heavier land may need up to two passes with a power harrow to achieve a favourable seedbed but, where soil and weather conditions allowed, seedbed cultivation and drilling was completed in a single pass with an implement combination to save both time, labour and energy input.

One area that could create problems, if not managed effectively was the naturally-acidic soil, and lime is an important treatment to maintain the correct pH balance for arable cropping in particular and in general it is applied every two or three years according to soil test results which are also used in determining fertilizer requirements.

As nutrient management has become more sophisticated, mineral fertilizer use has fallen significantly. Phosphate and potash applications, for example, were fine-tuned to each field, first to replace what the previous crop had removed, secondly to maintain the soil nutrient status required by the following crop. Nitrogen was applied in liquid form through a sprayer-type applicator for accuracy, resulting in even applications across the crop and ensuring fertilizer was kept away from water courses and hedge bottoms, where it could otherwise upset the natural order among grasses and other wild plant species.

The 160-head suckler cow herd represents an important enterprise, producing more than 150 beef animals annually. The herd comprises mainly Aberdeen Angus crosses, with Hereford/Friesian and Simmental crosses making up the rest, together with half a dozen belted Galloway. Replacements were bought in from a nearby farm selected on the basis of their good mothering qualities, hardiness and milk production.

Calving took place in straw-bedded byres from February to May, before the herd was turned out to graze the permanent hill pasture for the summer months. The young animals were weaned and brought indoors in October and the suckler cows at the end of the year, into deep-strawed covered yards for the winter. Principles of good stockmanship were keenly upheld and medication was used only where deemed essential to maintain herd health: the cows being vaccinated before calving, for example, and the calves wormed at housing. Good housekeeping, which involves ensuring the cattle sheds being kept clean and tidy when unoccupied, further helped to reduce possible disease and pest problems. The bull calves were kept entire and sold fat at ages of 12-14 months. The heifers were (usually) finished off on a silage/maize gluten/barley diet at the same age.

Yard manure, accumulated over the winter months, provided a valuable organic fertilizer, high in fibrous material, for the arable ground. This provided additional nutrients which could be balanced with reduced rates of inorganic fertilizers to improve the soil structure and organic matter status, illustrating the true integration adopted on the mixed farm.

Although the above are very different examples of mixed farms, the core systems that they represent are identical in that a fully integrated approach requires attention to detail in all parts of the farm business based on informed management decisions.

Adoption of IFM by others - self help technology transfer

Finally, whilst the LEAF Demonstration Farms and others throughout Europe provide an excellent approach for discussion to allow farmers to consider the options that they could adopt on their farm, LEAF also recognizes that there is a need to develop an approach for farmers to use, so that they could adopt IFM on their farm as a site-specific approach to improving their farm and adopt a more integrated approach. Thus, LEAF developed technical information on IFM, including the LEAF Audit. This self-assessment management tool provides a focus to help farmers objectively assess and improve their farming practices along IFM principles. Designed as a series of self assessment forms, the audit provides a convenient and structured way that, when carried out on an annual basis, monitors farm systems and helps to determine priorities at the farm to adopt a fully integrated approach.

The audit is divided into seven individual modules that include:

- Organization and planning;
- Crop protection;
- Energy efficiency;
- Animal husbandry;
- Soil management and crop nutrition;
- Pollution control and waste management;
- Landscape and wildlife features.

Each module is formulated as a series of questions that principally document each decision-making process a farmer takes. Consequently, it provides credit for where farmers have got it right, identifies areas where action is required and highlights priority areas that need to be addressed. It is site-specific and not a prescriptive or pass/fail document, but more geared towards systems and informed management choices. Furthermore, benefits include:

- Improving economic performance;
- Enhancing environmental performance;

- Meeting insurance requirements;
- Gaining a marketing edge;
- Ensuring environmental protection;
- Meeting legislative requirements;
- Addressing public concerns.

The aim of the LEAF Audit is to encourage continuous improvement and increase awareness and knowledge of what can be done. Now in its fifth year of use in the UK, the farmers who have adopted this approach have found it a useful management aid and more specifically 'it makes them think'.

Commercial and financial viability are vital for the long-term survival of the farm business. Any farming system has to be profitable to assure enhancement of environmental features and wildlife habitats on and around the farm. It is essential that we husband our resources, in particular the environmental resources on the farm of soil, water, air and areas of particular environmental sensitivity and value. Economic activity and growth are essential, but we must not be wasteful and we must minimize any environment damage.

As has been emphasized, LEAF does not advocate a prescriptive approach, but is committed to:
- Economically viable farming with the production of a continuous supply of high quality, safe, wholesome food;
- Minimizing the reliance on inputs, such as fertilizers and biocides, by actively considering alternatives;
- Efficient and responsible use of organic farm manures and crop residues to ensure that they do not act as a threat to the health of soil, water, wildlife, humans and animals;
- Maintenance and improvement of site-appropriate ecological diversity and wildlife habitats;
- Maintenance and improvement of landscape and farm buildings together with the amenity value of the countryside.

Integrated Farm Management is considered as a positive way for farmers to meet economic criteria and address the environmental concerns of the general public. Not only does the attention to detail demanded from the system minimize the risk to environment but the initiative involves the whole farm and the whole industry. LEAF believes such an approach can enhance farmers' opportunities, reassure customers and improve our environment. IFM is, however, a dynamic process and more work is required to encourage farmers to adopt it and study the fully interactions and benefits of the IFM approach.

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Mixed farming at a regional level: A more sustainable alternative to intensive agricultural systems and its application to the Central Ebro valley (Spain)

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Introduction

Animal production represents around 60% (approximately 1100 millions of ECU) of the economy related with farming activities in Catalonia, in the north-east of Spain. Pig production is specially important and represents almost half of the livestock production in Catalonia (Gabinet Tècnic del DARP, 1995) which produces almost 30% of whole Spanish pig production. Livestock activities tend to concentrate in certain areas where, if too high, they create environmental problems, mainly due to manure surpluses. At country scale, it has been estimated that manure can supply the major part of nutrients that crops can take up and in certain areas there is an important surplus of nutrients from those animal by-products (Junta de Residus, 1996).

More than 30% of the livestock production in Catalonia is concentrated in the area around the lower part of the Segre river (tributary of the Ebro river) where pig industry (40% of the total in Catalonia) is specially important (Junta de Residus, 1996). This is an inland, Mediterranean climate area with low annual average precipitation, 300 to 400 mm, quite variable among years and with ubiquitously distributed calcareous soils (Porta & Herrero, 1983; Herrero *et al.*, 1993). It comprises more than 300,000 ha of agricultural land.

In this area, two main cropping systems are practised that are very similar to those in a large area of the central part of the Ebro valley. The first one is rainfed with barley as the main arable crop in the northern part and almond and olive orchards in the south. The second one is irrigated with two main types of crops: the most important ones are arable crops (maize, wheat and lucerne), which usually are included in a rotation, though maize can be grown, as well, as monoculture; in a lower proportion there are fruit orchards (45000 ha), mainly apple, pear and peach. The irrigated area is formed by the junction of three main irrigation schemes (Canals d'Urgell, Pinyana and Catalunya i Aragó) and several small ones, which together represent over 150,000 irrigated hectares. Surface irrigation is, by large, the most important system used. Consistently, irrigation efficiency may be low in medium textured shallow soils which occupy quite a large area. Run-off and drainage water are in many cases re-used to prevent water shortage in late summer. Some parts of the area have salt-affected soils at different degrees.

In the Central Ebro valley of Catalonia, more than 60% of the farms are smaller than 10 ha and the number of farms larger than 100 ha is very small (Institut d'Estadística de Catalunya, 1989), although in recent times average farm area is increasing. Each single farm is usually composed of several fields, scattered around. Under these conditions, irrigation is the only way to maintain a profitable and sustainable agricultural system. At this moment, various projects are under development aiming to irrigate 100,000 ha additionally.

Due to intensification and specialization that has taken place in agricultural activities during the last decades there has been an expansion of livestock enterprises and a separation of farming activities between animal and crop production (Danés *et al.*, 1995). These conditions and the already mentioned lack of large enterprises make development of mixed farming systems in the traditional sense impossible. Nevertheless, it is not wise to renounce the benefits of mixed farming, mainly with respect to nutrient management. To contribute to sustainability of the system, it is necessary to recycle nutrients between subsystems, animal and crop, and in this case it has to be done at a larger scale. In the system described above, cases of mismanagement have been detected especially in the flow of nutrients from the animal subsystem to the crop subsystem (Navés & Torres, 1992; Torres Ciutat, 1995).

In the present work, we will focus on the flow of nutrients through soil manure application, from animal production into crop production subsystems in the Pla d'Urgell area. This area, which has a surface of 26,861 ha of agricultural land, is situated within the Canal d'Urgell irrigation scheme and can be considered a representative part of the irrigated agricultural system described above. The objectives of this study are to explore the possibilities to recycle nutrients from livestock wastes, to identify the main constraints that do not allow this recycling nowadays and to propose actions to overcome them.

Material and methods

The Pla d'Urgell is surrounded by an area with very similar farming system characteristics. It assumed that the net flow of manure is insignificant. Total amounts of available nutrients, N, P and K, present in livestock wastes have been calculated using data from Junta de Residus (1996) and Danés *et al.* (1995) relating to livestock production and nutrient contents in manures. Values for ammonia volatilization when manure is applied to the soil have been derived from Junta de Residus (1996) and ECETOC (1994).

Total crop and marketable yield uptake of nutrients and nutrient contents in crop residues have been estimated using data about land use (Gabinet Tècnic del DARP, 1996) and about crop fertilization needs from Danés *et al.* (1995) and Domínguez Vivancos (1989).

Present agricultural practices, use of livestock wastes and problems on their use were derived from Torres Ciutat (1995) and by means of a survey together with selected farmers, agricultural advisors and managers. The survey included questions about the use of organic wastes by farmers, crop rotations and their reasons for not to apply them and other information available, usual recommendations given by advisors and managers and technical problems on their application.

Results and discussion

Global balance

Type of manure produced, their nutrient contents and estimated ammonia volatilization coefficients are shown in Table 1. It is important to highlight that approximately 75% of N and P and almost 70% of K supplied in manures is coming from pig farms and they are mainly, if not all, produced in slurry form. This liquid manure is difficult to manage, due to its low nutrient concentration which increases costs in transport and reduces the distance to where it can be applied. If no major transformations occur, it should be considered as a by-product to be used, very close to the place where it is produced. Nevertheless, if the liquid manure is transformed, i.e. solid-liquid separation, its value increases such as the possibility to apply the liquid part through the irrigation system, in case proper agricultural practices are developed in the system.

Areas for different groups of crops, estimated nutrient uptake by crops and by marketable yield parts and nutrients available to return to the soil through crop residues are shown in Table 2. Uptake of nutrients takes place mainly by arable crops, especially cereals. Nitrogen uptake by lucerne is quite important but this originates from the atmosphere, although some farmers apply pig slurry to lucerne. Little is known about such practices and their nitrogen use efficiencies, but it can be reasonably assumed that this efficiency will be (relatively) low. Nevertheless, best management practices advise, in some situations, to apply about 40 kg fertilizer-N ha^{-1} before sowing of lucerne to ensure rapid establishment. Also, in the overall N balance the contribution of lucerne to the following crop should be considered; in general it is assumed that it can provide an important part (40 to 60%) of the nitrogen needed by the wheat crop grown after lucerne.

Part of the nutrients taken-up by crops may return to soil through crop residue incorporation. Nevertheless, part of these residues leave the cropping system when used as livestock bed or other purposes. Although it is difficult to estimate, we will consider that

Table 1. Main type of manure produced, total annual amount (Mg) of nutrients (N, P_2O_5, K_2O), present in manures and volatilization coefficient (%) for nitrogen from different types of livestock farms in the Pla d'Urgell (Catalonia) area. Elaborated from Junta de Residus (1996), Danés *et al.* (1995) and ECETOC (1994).

Type of Livestock	Type of manure produced	Total annual amount of nutrients in manure (Mg)			Volatilization coefficient for N (%)
		N	P_2O_5	K_2O	
Beef	Manure and slurry	541	267	352	8
Pig	Slurry	2716	2223	1396	15
Sheep	Manure	217	130	139	5
Poultry	Manure and slurry	222	252	160	10
Others	Manure	17	24	14	5
Total		3713	2896	2061	

Table 2. Area (ha) and total annual amount (Mg) of nutrients (N, P_2O_5, K_2O) taken-up by crops, present in marketable yields and in crop residues for different types of crops in the Pla d'Urgell (Catalonia) area. Elaborated from Gabinet Tècnic del DARP (1996), Danés *et al.* (1995) and Domínguez Vivancos (1989).

Crop	Surface (ha)	Total annual nutrient crop uptake (Mg)			Total annual nutrient uptake in marketable yield (Mg)			Total annual residue nutrient content (Mg)		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Arable										
Maize	4759	1599	628	1314	914	400	286	685	228	1028
Wheat	4859	875	467	846	625	359	211	250	108	634
Lucerne	7342	2467	617	2026	2467	617	2026	-	-	-
Other	3525	613	317	571	409	231	286	205	87	286
Orchard										
Apple	2750	206	74	305	42	18	123	133	29	152
Pear	1572	87	25	119	18	6	48	56	10	59
Other	718	124	19	112	21	5	26	89	14	82
Total	25525	5971	2147	5293	4496	1636	3006	1418	476	2241

only 50, 50 and 100% of the residues of cereals, other arable crops and fruit orchards respectively, are returned to the soil.

The situation is different for N, P and K when available nutrients from manure and total nutrient crop uptake are compared. Surveys by Virgili Sanromà (1994) and Torres Ciutat (1995) showed that a large number of soils in the region have available K contents ranging only from medium to low. Under the present fertilizer recommendations those soils should be fertilized. The needs of potassium by crops largely exceeds the available K in manure, but in this case returns from residues are very important. However, when the residue returns are taken into account there still is a shortage of that nutrient. Additionally, most of the crops grown in the system are responsive to K fertilization whereas certain crops, such as apple trees, need equilibrium K fertilization to maintain fruit quality when they are stored under cool conditions for a long time. So, even in the most favourable case, manure will be unable to supply all K needed by crops and fertilizer-K will still have to be applied.

For phosphorus, the amounts present in manure and crop uptake are very similar. If P incorporated into soil through crop residues is considered, there is a surplus of available P for crops. On calcareous soils, a large proportion of P is immobilized by adsorption or precipitation with calcium (Hagin & Tucker, 1982; Matar *et al.*, 1992) and there is not a direct relationship between P applied and P available for crops. Many soils are now rich in available P (Virgili Sanromà, 1994; Torres Ciutat, 1995) but field experiments have shown some P responsiveness (Bosch Serra, 1996). Nutrient imbalances may also be important (i.e.: P/Zn in maize, iron chlorosis, etc.), although under field conditions this is difficult to observe (Sumner & Farina, 1986). So, some fertilizer-P should be provided, especially in localized form (Bosch Serra, 1996). Strategic P-enrichment of the soils might be considered, but that can cause environmental problems (Sharpley & Rekolainen, 1997).

Nitrogen uptake by lucerne is considered as coming from atmospheric fixation. The rest of N taken up by crops is slightly less than N present in manures. Nevertheless, if ammonia volatilization coefficients are considered, N supply through manures is insufficient to cover crop N requirements. When N incorporated into soil through crop residues is considered, an almost zero global balance could be achieved. Leaching losses may also be important (Domingo Olivé *et al.*, 1997) and have to be taken into account. In general, it might be stated that even in the best case there will be a shortage of nitrogen to maintain present yields only with the use of N from manures.

Present status of manure use

The survey showed that the use of organic fertilizers is not ubiquitous and homogeneous in the area. First of all, manures are mainly applied to cereal crops. Lucerne and orchards are rarely fertilized with organic manures. When cultivating these crops, soils are rarely ploughed and incorporation of manures into the soil is not possible. Many farmers are reluctant to use organic manures, especially pig slurry, as organic amendment or as fertilizer for crops. Various causes have been put forward for this reluctance. On one hand there have been unfavourable experiences in the past, probably related with very high rates of application. On the other hand, there is lack of information, not only among farmers, but also among advisors and managers, on the use of these livestock wastes. Recommendations on the use of livestock wastes are usually not incorporated in fertilization plans and, when applied, these manures are not considered as fertilizer applications and inorganic fertilizers are applied at a normal rate. A balance of soil nutrients for different crop rotations (Torres Ciutat, 1995) showed that when livestock wastes are applied, this balance is clearly positive; only when inorganic fertilizers are used it is approximately zero.

Technical problems are related to the lack of (*i*) available machinery to inject or to incorporate quickly slurry into soil which would increase N use efficiency, (*ii*) equipment to apply N in growing maize, (*iii*) large equipment to apply slurry at longer distances from the source, (*iv*) technical tools to easily estimate nutrients from manure doses, (*v*) realistic figures about N manure dynamics under present climate and farming practices and (*vi*) proper characteristics of manure, i.e. uniformity of composition or solid-liquid separation for irrigation purposes.

Towards a more realistic approach

A more realistic approach than using global balances is to consider, for N, only those crops, where farmers mainly apply livestock wastes (wheat and maize). If we consider on one hand nutrient uptake by crops and on the other nutrients re-introduced to soil by means of crop residue incorporation and via manuring, we observe a surplus of N, P and K from livestock wastes in many fields. As discussed before, application of those surpluses to the soil may be acceptable for P and K in the short-term, but application of N surpluses will lead to environmental problems. The difficulty to split soil applications of manures for cereal crops is a major problem to utilize N from manures efficiently. If we consider than that not more than 50% of the N should be applied before sowing of cereals, the surpluses of nitrogen from wastes become higher. It is clear that maximization of the use of livestock wastes as fertilizer for crops in a efficient way can not be achieved under the present management conditions. Various aspects need further consideration:

- Application of manures at a correct rate, which is linked to the increase in the area fertilized with livestock wastes. This may be done by making information available to farmers and advisors and also by making the product easily available to farmers (concentrating wastes in large tanks, special companies for the application of wastes).
- Application of manures during the course of the growing season can only be done if they are in liquid form. Only the liquid fraction of slurries can be applied through the irrigation system. Therefore, it is necessary to increase the amount of slurry that is treated to separate the solid from the liquid fractions. An increase in the overall efficiency and uniformity of the irrigation system would also increase the uniformity of slurry application and the efficiency of N utilization.
- To avoid losses to the atmosphere, it is necessary to incorporate manures, mainly slurries, into the soil as quickly as possible or to inject them. Currently, the traditional equipment used for applying slurry is unsuitable for this purpose, leading to major volatilization losses.

Increasing the efficiency of N from manure will result in a build-up of P contents in soils in the long-term. This problem should be tackled in the future. Some approaches seem feasible (i.e. modification of animal diets) but they are not yet available. In the meantime, treatment of manures which would allow net outflow of nutrients could help. Changes in the livestock structure should also be considered (i.e. specialization in piglets instead of meat production).

Soil information will be crucial to deal with the problem. Knowledge of soil type, soil test levels and programs for soil monitoring are needed.

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Agroforestry in temperate Europe: History, present importance and future development

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Introduction

Agroforestry – the deliberate combination of annual or perennial crops and trees – developed as a science in the 1970s. It focused on sustainable, low-input intensification of agricultural production in tropical, developing countries through synergies between crops and trees or shrubs. More recently, agroforestry has also been proposed as an alternative form of land use for temperate, industrialized countries. There, agroforestry is used as a means to reduce overproduction of agricultural commodities, to diversify farm income and to generate beneficial environmental effects.

Agroforestry is a relatively new scientific discipline, but an ancient practice that farmers have used throughout the world (Nair, 1993). In this contribution, a summary will be given of the history of agroforestry in temperate Europe and a few present-day applications will be discussed. I will then try to infer on the future prospects and major drawbacks of agroforestry for temperate Europe.

The history of European agroforestry

Originally, European agriculture was based on shifting cultivation. Tree-based agricultural systems are reported from Roman times (Lelle & Gold, 1994) and until about two centuries ago, many European forests were significant sources of food and were grazed with ruminants and pigs (Brownlow, 1992). Actually there was no distinct boundary between forest and agricultural land and the input of organic matter and energy, necessary to keep agriculture sustainable came from forests in the form of fodder, litter and wood (Haber, 1994). As an example, Eckert (1995) estimated that in the Neidlingen valley (Baden-Wurttemberg, Germany) until about 1500, the forest provided three quarters of the nitrogen and 90% of the phosphorus available for the fertilization of fields, vineyards and gardens.

In the 18th and 19th century, intercropping on cleared forest land between rows of planted or sown forest trees was common practice in many forest districts in Austria, Belgium, France and Germany (Beil, 1839; Kapp, 1984). When industrialization made labour more expensive and agronomic progress allowed maintenance and restoration of soil fertility without having to recur to reforestation, European agroforestry practices started to decline (Kapp, 1984). Trees were increasingly banned from agricultural land, mainly due to agricultural mechanization linked to the pressure for increased labour productivity, to land reallocations in the process of consolidations of fragmented holdings and to increasing specialization of farming enterprises.

Table 1. Some present day agroforestry systems in temperate Europe.

System	Regional Distribution	Selected References
Forest grazing	Alps	Greif (1992); Von Maydell (1994)
Wooded pastures	Jura mountains (Switzerland)	Gillet & Gallandat (1996)
Hedgerows, windbreaks	Western, central, and eastern Europe	Bazin & Schmutz (1994); Burel (1996)
Riparian buffer stripes	Western, central, and eastern Europe	DVWK (1997)
Streuobst	Western, central, and eastern Europe	Lucke *et al.* (1992); Herzog (1998)
Forestry with pig and boar husbandry	UK, Yugoslavia	Djordjevic-Milosevic *et al.* (1997); Brownlow (1994)
Fruit tree intercropping	France, U.K.	Newman (1986); Dupraz & Newman (1997)
Forest tree intercropping	Czech Republic	Edessa (1997)

Nevertheless, a number of systems still persist today. Some can be found at particular locations only, whereas others are fairly common (Table 1). Silvopastoral agroforestry is mainly practised in mountainous regions. In the Jura mountains of Switzerland, there are approximately 52,000 hectares of wooded pastures between 900 and 1400 meters above sea level (BFS, 1993). They consist of spruce (*Picea abies* Karst.) at low densities on natural meadows, typically grazed with cattle and/or horses at 0.5-1.5 large animal units per hectare (Gillet & Gallandat, 1996). In alpine mountain agriculture, forest grazing is still a source of fodder. Towards the end of summer, when the pastures become exhausted, the animals are often driven into nearby forests. Greif (1992) estimates that in Austria, legal regulations permit pasturing of about 400,000 hectares of forest, feeding more than 80,000 head of cattle and 55,000 head of sheep and goats (Von Maydell, 1994).

Hedgerows and windbreaks still characterize many European agricultural landscapes. There are numerous accounts of their former and present frequency and their ecological interactions with the surrounding farmland (see, for example, Bernacki, 1994).

Fruit trees were traditionally grown on agricultural land undersown with crops or grassland ('streuobst'). Until the 1950s, both silvo-arable and silvo-pastoral forms existed; today the silvo-pastoral type dominates. Since the 1930s, streuobst has been under continuous decline due to the development of intensively managed dwarf-tree orchards. However, even today, it still occupies about one million hectares in ten European countries and has a considerable, though largely unrecognized, impact on the European fruit market (Herzog, 1998).

Properties of present-day agroforestry systems

The general features of present-day agroforestry in the European context can be summarized as follows:

- The *ecological* effects of agroforestry are positive. The presence of trees in landscapes contributes to biological diversity at the genetic, species and ecosystem's level. Streuobst, wooded pastures, hedgerows and windbreaks contain numerous physical structures that lead to ecological gradients (dry - moist, shaded - sunny, exposed to - protected from wind). They form a variety of ecological niches and offer a range of habitats for plants and animals with different environmental requirements (Bünger & Kölbach, 1995; Herzog & Oetmann, 1997). Shelterbelts and riparian buffer stripes reduce wind and water erosion and the leaching of nutrients and pesticides into the groundwater and the surface water (Schultz *et al.*, 1994). Trees are a sink for CO_2 and thus might help to mitigate the rise of its content in the atmosphere (Schroeder, 1994).
- The *socio-cultural* properties of agroforestry systems are generally advantageous. Trees represent a cultural value and find wide public acceptance as a symbol of life and nature. The visual quality of most traditional European agricultural landscapes is related to the harmonious contrasts between various landscape elements, i.e. darker forest, structured arable fields and green meadows, interspersed with small woods, hedgerows, etc. (Lucke *et al.*, 1992). Due to their size, trees provide a contrast to low level agricultural crops, and serve as land marks for orientation.
- The *economic* performance of traditional agroforestry systems is generally insufficient. For streuobst, an annual loss per tree of ECU 0 - 55 has been estimated due to comparatively low labour productivity (Dabbert, 1994; Rösler, 1996). Planting of hedgerows, buffer stripes, etc. takes place only if subsidies are available.

Traditional European agroforestry systems were developed by farmers for purposes of production (fruits, wood, fodder, various non-timber tree products) or to delimit field borders (hedges). These goals can now be achieved by other means or by more efficient production systems, and no longer justify the existence and maintenance of agroforestry. In the last years, however, the awareness has increased that landscapes fulfil multiple functions (De Groot, 1992) and that the presence of trees in landscapes is important for maintaining biodiversity, for the water and nutrient balance of the landscape and for its aesthetic and recreational quality. Therefore, the remaining agroforestry systems receive support from - mainly - proponents of nature protection and, in many European countries, they are now protected by law. There are attempts to re-establish hedgerows and riparian buffer stripes.

Novel agroforestry systems

Towards the end of the 1980s, the development of novel European agroforestry systems has started. This resurgence of interest in agroforestry is the result of internal political, social, economic and environmental pressures and of perceived necessity to reduce timber extraction from tropical forests (Sibbald, 1997). In Great Britain and France, research networks have been established, where different combinations of trees with crops and/or animals are examined at a variety of sites representing the major climatic and soil conditions of these countries. Mainly hardwood trees (e.g. *Juglans* spp., *Prunus avium* L., *Alnus* spp., *Fraxinus excelsior* L., *Acer pseudoplatanus* L.) and poplars (*Populus* spp.) are being tested at densities of 50 to 400 stems per hectare (Dupraz & Newman, 1997). The overall extent of test sites in the European Union is estimated at 350 hectares (Pointerreau, 1997, pers. comm.).

The scope of these novel agroforestry systems is to combine the advantageous external effects of traditional agroforestry with improved operational efficiency, i.e. by allowing for mechanized labour. The production of high-quality hardwoods suggests a promising marketing opportunity (Dupraz & Newman, 1997). Willis *et al.* (1993) argue that the development of new, fast growing poplar clones has made poplar intercropping an economically competitive land-use alternative. These assertions are, however, based on modelling and prospective costs and prices, including major uncertainties.

From an agronomic viewpoint, agroforestry systems are more difficult to handle than agricultural monocropping and demand additional knowledge. The interactions between trees and crops need to be managed in such a way, that undesirable effects are minimized and positive interactions stimulated. For hardwood production, the trees must be managed to grow satisfactorily to yield a high-quality log. Agroforestry requires a long-term commitment and will reduce the flexibility of the farmer in resource and land allocation. These are some factors that limit farmers acceptance.

Conclusions

Agroforestry – traditional as well as novel systems – receives a good share of goodwill from the wider public. It offers 'something that appears closer to a natural ecosystem than conventional agriculture or forestry, which is potentially permanent, and which offers diversity of products, sustainability of production and protection of the environment, possibly with low inputs or combined with organic farming' (Carruthers, 1990, p. 150). Maintenance of existing and spread of novel systems will not be possible without a favourable institutional setting, including the appropriate allocation of subsidies. Their justification is based on the external benefits that agroforestry can generate. The public goods provided by agroforestry increase its social efficiency, which is more relevant than private efficiency in evaluating the sustainability of land-use systems (Barbier, 1990). If external costs and benefits are internalized and environmental products and services are rewarded financially, diversified land-use systems have a comparative advantage over monocultures.

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Ecological effects of changes in mixed farming on the Hebridean island of Tiree (Scotland) between 1960 and 1997

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Introduction

The Hebridean island of Tiree (180 km NW of Glasgow) is 15 km long and up to 8 km wide with an area of 84 km^2. It is mostly low-lying, with extensive areas of herb-rich calcareous pastures formed from wind-blown shell sand - the machair (Vose *et al.*, 1956; Crawford, 1997) – surrounding a core of mire and acidic heathland – the sliabh.

Much of the machairs and other areas of good agricultural land are divided into numerous small farm units (crofts), but extensive tracts of machair and most of the sliabh remain as unenclosed common grazing lands (Coull, 1962; Harrison, 1989), the use of which is generally restricted to occupiers of ground within a given township. There are approximately 250 crofts, but many are worked together, so that the number of active businesses is about 90 (D. Harrison, pers. comm.).

Tiree is of considerable nature conservation interest. In addition to the botanical interest of the machair, the island supports approximately one quarter of the UK population of corncrake *Crex crex* (Royal Society for the Protection of Birds – RSPB, 1994-97), mainly on enclosed croft land, and extremely high densities of breeding waders (Shepherd *et al.*, 1988; Shepherd, 1989), mostly on the unenclosed machairs.

Ecological focus

Tiree forms part of the Argyll Islands Environmentally Sensitive Area (ESA) established under EC Regulation 2078/92. This scheme aims to 'support the continuation of *farming and crofting practices which have ... maintained wildlife habitats* and to encourage measures that will enhance the environment' (Scottish Office Agriculture Environment and Fisheries Department – SOAEFD, 1994). ESA literature describing the area and the biological interest emphasize the 'traditional' nature of land management practices, but rarely, if ever, any evidence of past land-use is presented in an ecological perspective.

Previous studies have commented on the change in various land uses (e.g. Harrison, 1989), determined from the Scottish Office's parish-based agricultural census data. This study attempts to integrate these figures in a spatial context and to point out aspects to the changes not evident from the census figures.

We consider the possible impact of these land-use change on biodiversity, and in particular on the corncrake (*Crex crex*) for which the island is a notable stronghold in the British Isles. We comment on the consequences of these past practices in the context of cropped land and evaluate the effectiveness of the scheme in supporting or reinstating this traditional management.

Study area

Two areas, consisting of one and two townships, respectively, were chosen for the study: Balemartine is situated in the Southern part of the island and is divided into 9 crofts; Greenhill and Kilkenneth are in the extreme West and have 17 and 8 crofts, respectively. The croftland of these three townships contain some of the highest densities of calling male corncrakes in the British Isles (RSPB, 1994-97).

The study compares the cropping pattern in 1959-60 with that in 1997. Data for 1959-60 were obtained from maps and data sheets produced as part of an extensive, mostly unpublished, survey of the Hebrides by Dundee University and is quoted by kind permission of Prof. J.B. Caird. The 1997 data were collected in the field in early 1998 and checked against a 1:10000 colour air photography. Areas were measured to a precision of 0.1 ha and lengths measured to the nearest 10 m.

Results

Previous studies (Harrison, 1989) have shown how the area of cropped land has dropped continuously since 1940, as a combination of 'meadow' hay and arable rotation gave way to a regime dominated by the cutting of silage from permanent leys. This, to some extent reflects the shift in livestock management from cattle to sheep (1960: 3463 cows, 5712 ewes; 1992: 1697 cows, 7512 ewes). However, this change in emphasis should not be taken as an universal reduction in intensity of croft management – some of the larger, more active crofters have intensified grassland management, but have nevertheless abandoned arable cropping rotations.

In the study area, the drop of 34% in the overall area cropped (i.e. of arable plus hay/silage) reflects the trend for the island as a whole. In 1960, there were 62 parcels of arable cropping totaling 33.6 ha, of which 48 (28.6 ha) were grain crops (Figure 1, Table 1). In 1997, there were only 8 parcels (2.2 ha) of which only 4 were of cereals (1.5 ha).

By contrast, the figures for cut grass illustrate some of the underlying complexity hidden in the parish figures. The total area cut has increased 22%, but this is almost wholly accounted for by the fertile ground in the south of the township of Greenhill (where crofters from Kilkenneth and the adjacent townships of Balemeanach and Moss have concentrated their silage production). In Balemartine the area of grass cut has remained constant but there has been a shift in the occurrence of this management within the township – many of the outlying fields that were previously cut are now used only for grazing and grass production is concentrated on the most productive soils. This is reflected in the mean size of cut grass parcels in 1997 (1.18 ha) as compared with 1960 (0.56 ha).

The *type* of the grass crop has also changed everywhere, except in Kilkenneth, where the two resident crofters are amongst the most traditional on the island which is reflected by the fact that the land adjacent to the croft houses has remained in arable rotation. Over the three study townships, 57% of the grass cut was part of an arable rotation in 1960 and cut

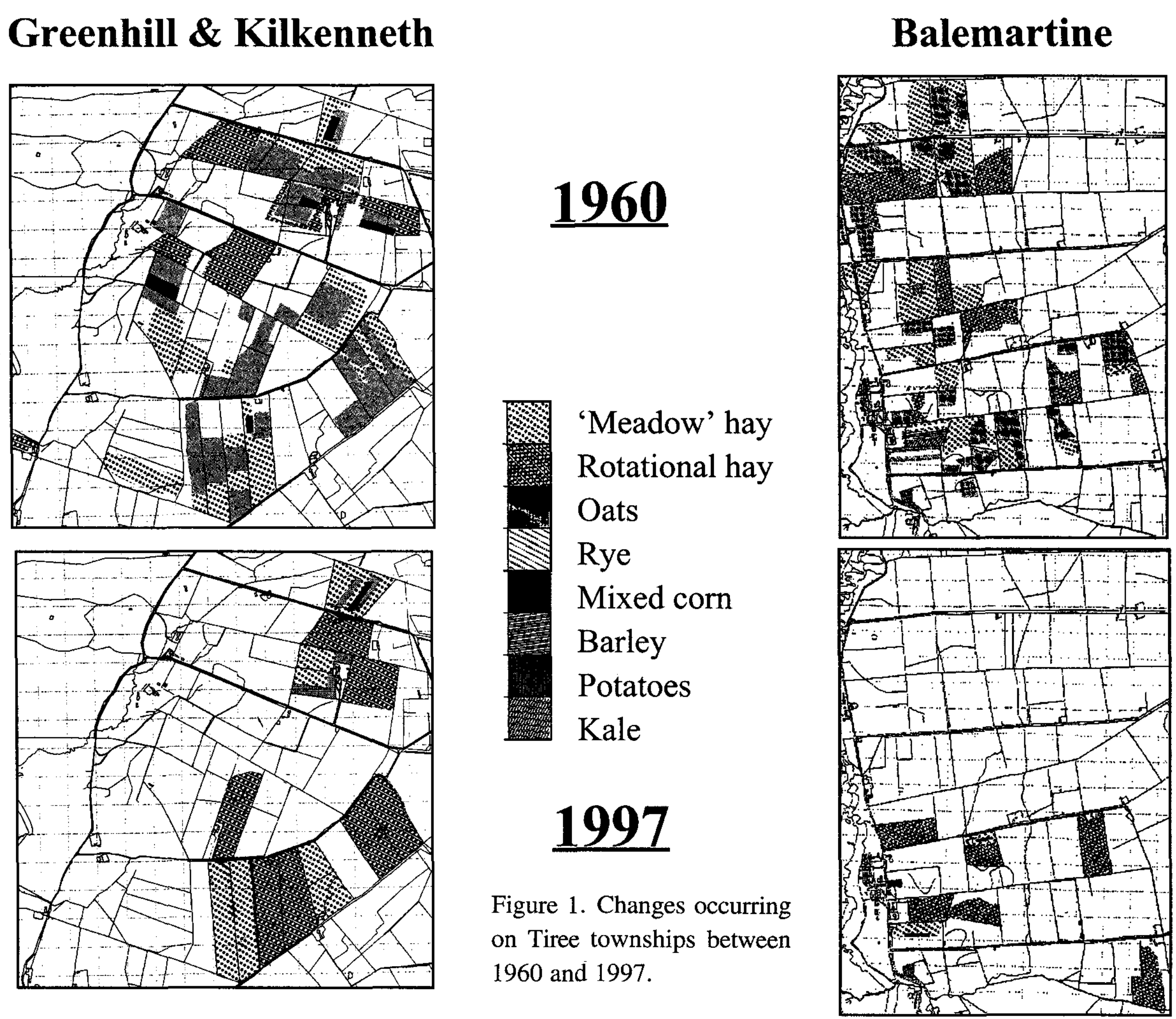

Figure 1. Changes occurring on Tiree townships between 1960 and 1997.

Table 1. Changes occurring on Tiree townships between 1960 and 1997.

	1960	1997
Area of cropped land (ha)		
Balemartine	22.1	11.1
Greenhill	24.0	23.7
Kilkenneth	23.5	11.2
Sum of three townships	*69.6*	*46.0*
Number of cropped parcels		
Balemartine	53	12
Greenhill	29	8
Kilkenneth	22	9
Sum of three townships	*104*	*29*
Mean parcel size (ha)		
Balemartine	0.42	0.92
Greenhill	0.83	2.96
Kilkenneth	1.07	1.20
Mean of three townships	*0.67*	*1.59*
Area of cereals (ha)		
Balemartine	10.0	0.0
Greenhill	11.6	0.0
Kilkenneth	7.0	1.5
Sum of three townships	*28.6*	*1.5*
Area of cut grass (ha)		
Balemartine	10.5	10.6
Greenhill	11.8	23.7
Kilkenneth	13.7	9.5
Sum of three townships	*36.0*	*43.8*
Length of crop/crop and crop/other ecotone (m)		
Balemartine	10570	3640
Greenhill	8230	5070
Kilkenneth	8170	3650
Mean of three townships	*26970*	*3650*
Length of ecotone per cropped hectare (m ha^{-1})		
Balemartine	478	328
Greenhill	343	214
Kilkenneth	348	326
Mean of three townships	*387*	*269*

permanent grass (the 'meadow hay' or 'natural hay' of the Dundee survey) was limited to the ground where ploughing was inappropriate. In 1997, 67% the grass leys were over 5 years old, and of the 14.4 ha of 'temporary' grass, only 5.4 ha comprised part of an on-going arable rotation (by the 2 Kilkenneth crofters).

Taking the data for *all* cropped parcels, mean parcel size has increased by 37% (though this figures masks larger increases in Balemartine in particular). In addition, the length of the ecotone (the edge between two distinct land cover types) has dropped by 30%. There are now very few ecotones around cropped areas other than hard field boundaries such as fences and walls.

Biodiversity loss

Despite the scale of these changes, the implications of the decline in arable habitats and arable/grass mosaics for conservation has received little recent attention in the Argyll Islands. Some indication of the possible effects can, however, be gained from studies on the Outer Hebridean islands of The Uists.

For example, on The Uists, arable cropping is known to support a variety of rare or declining plant species and habitats. Arable weed communities are common (Crawford, 1990), not at the least because of the shallow ploughing necessary to prevent erosion of the sandy soil (Grant, 1979). In addition, cropped areas in the Uists are used by nesting oystercatchers (*Haematopus ostralegus*) and ringed plover (*Charadrius hiaticula*) (Fuller *et al.*, 1986) and there is evidence that the former prefers the fallow/grass ecotone ecosystem over both grass and fallow alone (Wilson, 1978). Flocks of wintering twite (*Carduelis flavirostris*) also make use of cereal stubbles for foraging and corn bunting (*Miliaria calandra*) is still common on the Uists (Williams *et al.*, 1986) while its decline on Tiree has been documented by Cadbury (1989) and Craik (1997).

The change in the nature of the grassland replacing the arable cropping also has implications for the corncrake. According to the most recent RSPB guidance on habitat management for corncrake (in prep.), optimal breeding success requires four elements:

- Vegetation cover early in the season (April-June), mostly in tall herbs;
- Hay or silage fields;
- Harvesting of the fields in a manner least likely to damage chicks;
- Cover late in the season after the grass harvest.

Early vegetation cover and hay/silage

Radio-tracking work by Tyler (1996) in the Shannon Callows (W. Ireland) and on the Hebridean island of Coll have demonstrated clearly that corncrakes are birds of meadowland and avoid short pasture at all times of the year. In addition, this work has shown that corncrakes do not preferentially use hay or silage fields as compared to 'early cover' species such as *Phalaris*, *Iris*, *Phragmites*, *Urtica* or umbellifers. For example, evidence from nature reserves on Coll and Orkney suggest that the birds will limit themselves throughout the breeding season to areas of non-grass 'early cover' where those areas are large enough (C. Self, RSPB, Coll, pers. comm.; R. Simpson, RSPB, Orkney, pers. comm.).

The changes on Tiree, documented in this paper, suggest that the area of short pasture has increased as the number of fields containing cropped ground has decreased. However, information provided by individual crofters suggests a more complex pattern. While the fields of active crofters are more likely to be heavily grazed than in 1960, there are a number of crofts that are totally abandoned or grazed for only very short periods of the year. Inspection of maps of calling male corncrakes produced annually from Tiree (RSPB, 1994-97) also suggests that the distribution of birds is not closely correlated with that of hay/silage fields, but rather trend to the field margins and the edges of wetlands (the ecotones).

'Corncrake-friendly' mowing

Anecdotal evidence from the Shannon Callows suggests that the mowing of grass grown in strips is less of a threat to corncrakes than mowing of larger fields (R. Green, RSPB, pers. comm.). However, the changes in the geometries of fields are not simple and have been accompanied by a general increase in the efficiency of mowing equipment. It is, therefore, not possible to make a judgement on the net effect on bird kill of the changes in plot size and shape.

Late vegetation cover

'Late vegetation cover' can be composed of much the same plant species and in the same areas as 'early cover' and advice from RSPB (*op.cit.*) concentrates on these areas. However, it is widely reported by local farmers and crofters that corncrakes used to utilize cereal crops, particularly in August, when they would move in, when hay fields were cut (e.g. Alister MacDonald, crofter, Drimnin, pers. comm.).

We, therefore, suggest that the trends in management amongst *active* crofters, that is a concentration of grass production in a few large fields and a reduction in the late cover provided by cereal crops, may be working against the interest of the corncrake, but that the amount of habitat unaffected by crofting change (wetlands and field margins) and the positive benefits of croft abandonment in some instances are masking this effect, i.e. birds are redistributing in response to concurrent intensification and abandonment.

The Argyll Islands ESA

To-date, concern over the implications of agricultural change for biodiversity in Tiree have largely centered on three main issues (as reflected in the prescriptions of the ESA): the impact of changes in grassland management practices for corncrakes (voluntary prescription under ESA backed up by stand-alone RSPB/SNH (Royal Society for the Protection of Birds/Scottish Natural Heritage) payment scheme); impact of summer grazing of machair ground on the floristic composition and, to a lesser extent, on breeding waders (mandatory prescription); and the impact of draining and improving inbye ground on plants and birds (mandatory prescription).

The explanatory booklet for the Argyll Islands ESA Scheme (SOAEFD, 1994) lists up to 15 natural and semi-natural habitats upon whose management 'the valuable wildlife of the islands depends'. Unfortunately, arable ground is not listed among them. Arable cropping is nevertheless included amongst the possible management options under the scheme. However, it attracts a payment of only £ 170 ha^{-1} and is therefore less attractive than the payment for late, 'corncrake-friendly' mowing of grass fields (£ 180 ha^{-1}).

This low priority assigned to arable cropping is reflected in the fact that to the first author's knowledge (SAC/FFWAG data; Scottish Agricultural College/Farming Forestry and Wildlife Advisory Group), no crofter has changed his arable cropping pattern on the basis of the scheme and the number of crofters growing corn has not increased from the pre-scheme level (about 10 units on the whole island).

Conclusions

Decline in the degree of arable cropping and the knock-on effects on the pattern of grass production - the decline in mixed farming – has been one of the major land use changes in Tiree over the past 40 years. By contrast, there is little or no evidence that the area of inbye wetlands, for example, has ever been less than it is today. Yet, enhancement of wetlands and machair are priority habitats under the Argyll Islands ESA, while the scheme has done nothing to reverse the decline in the diversity of the central focus of croft activity – the cropped ground.

Cadbury's data (1989) indicating the decline in corn bunting has provided one possible effect on the biodiversity of the island. In addition, the implications of the changes described for the corncrake, along with that of the apparently increasing distinction between the management carried out by active and inactive crofters, is, we believe, a field requiring urgent attention. We fear that the message currently being given to those who work the land is, that the interests of conservation can equally be served by a set of barely-active individuals tenanting semi-abandoned crofts.

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MULTIFUNCTIONAL CROP ROTATIONS FOR MIXED FARMING SYSTEMS

Organic crop rotations for grain production

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Introduction

There is in organic farming a stronger interdependency between livestock production and crop choice than in conventional farming. The most common organic farming system in Denmark is based on a large share of grass-clover and fodder crops in the rotation, in combination with a stock of ruminant animals, typically for dairy production (Tersbøl & Fog, 1995). Under proper management, this farm type (0.9-1.4 livestock units ha^{-1}) has proven to sustain a stable crop production with negligible problems (Askegaard & Eriksen, 1997). Crop rotations with grass-clover fields and row crops have shown to be very robust in terms of resistance against weeds, pests and diseases (Holm, 1994). The rotations also receive a high level of nitrogen input from N_2-fixation in the grass-clover. In the first and second year, 100-250 kg N ha^{-1} yr^{-1} may be fixed depending on the clover content (Kristensen *et al.*, 1995).

The production of pork and eggs in Danish organic farming is expected to increase. This will lead to a larger fraction of cereals and pulses in the crop rotations (Tersbøl & Kristensen, 1997). As this fraction increases, the stability of the crop rotations can be assumed to decline. Effective weed control will then become more difficult (Rasmussen & Ascard, 1995), and the crops will be more dependent on imports of nutrients from outside the farm (Olesen & Vester, 1995). Such arable farms will depend on green manure crops for sufficient nitrogen supply. Catch crops will also play a role to minimize nutrient losses by leaching (Thorup-Kristensen, 1997).

These effects are explored at crop rotation level in a long-term experiment carried out at four sites in Denmark. The experiment focuses on the possibilities for a short and a long-term increase in grain production in organic farming. The effects of different crop rotation elements on yield, nutrient leaching, weed infestation and soil nutrient availability are investigated.

Material and methods

Four different four-year crop rotations are compared (Table 1). Comparisons can only be performed at rotation level, i.e. as an average of all crops in the rotation. Some crops with the same place in different rotations can, however, be directly compared. All fields in all rotations are represented each year. Three factors are included in the experiment in a factorial design:

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

The design of the rotation for each of the two levels of the catch crop is shown in Table 1, and the experimental factors at the different sites are shown in Table 2.

The ranking of the crop rotations represent a decreasing input of N through N_2-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.

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. The clover is established in oat and rotary cultivated in bands after harvesting the cover crop. The winter wheat is drilled into these bands at double normal row spacing. The clover is controlled during the growing season by cutting it separately with a brush weeder to reduce competition with the wheat. The grass-clover in Rotations 1, 2 and 3 is either a stand of white clover and five varieties of perennial ryegrass on the lighter soils, or the same mixture combined with red clover on the heavier soils.

The fertilized plots were supplied with animal manure (slurry) at rates corresponding to 40% of the nitrogen demand of the specific rotation. The nitrogen demand, based on a

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.

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 wheat
	Lupin	Peas/barley	Beet	Peas/barley
With	S. barley:ley	S. barley:ley	S. barley:ley	S. oats:clover
	Grass-clover	Grass-clover	Grass-clover	W. wheat/clover
	S. wheat:Grass	W. wheat:Grass	W. wheat:Grass	W. wheat/clover
	Lupin:Grass	Peas/barley:Grass	Beet	Peas/barley:Grass

Table 2. Experimental sites and treatments.

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

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 of grass-clover and peas/barley are set to zero. All straw and grass-clover biomass is incorporated or left on the soil in all treatments.

A spring barley crop with undersown ley was grown at all sites except Holeby where, in 1996, a winter wheat crop was grown. No pesticides were used in 1996. The experimental treatments started in 1997, but Rotation 1 did not fully comply with the design shown in Table 1. The design of Rotation 1 in 1997 was: spring barley:ley, grass-clover, grass-clover and peas/barley. The experimental sites represent all major Danish soil types and climate regions.

The size of the plots varied between sites from 169 m^2 at Flakkebjerg to 378 m^2 at Jyndevad. Short cut grass borders separated all plots to prevent movement of soil between plots. A soil border separated the crop of each plot from the grass border. This soil border was kept bare throughout the growing season by rotary cultivation 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. Each plot was subdivided into 3 to 5 subplots, of which two were used for determining yield. The other subplots were subdivided into mini-plots of 1 m^2 each. These mini-plots may be used for small investigations. An example of the plot infrastructure is shown in Figure 1.

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

Yield was measured in all plots, both at harvest and when incorporating plant material. The contents of nitrogen, phosphorus and potassium in the yield were measured. The soil content of mineral nitrogen was measured in spring. The occurrence of weeds, diseases and pests and nutrient deficiencies were recorded in all plots with cereals and pulses. Leaching of nitrogen and potassium was measured using porous ceramic cups in selected plots.

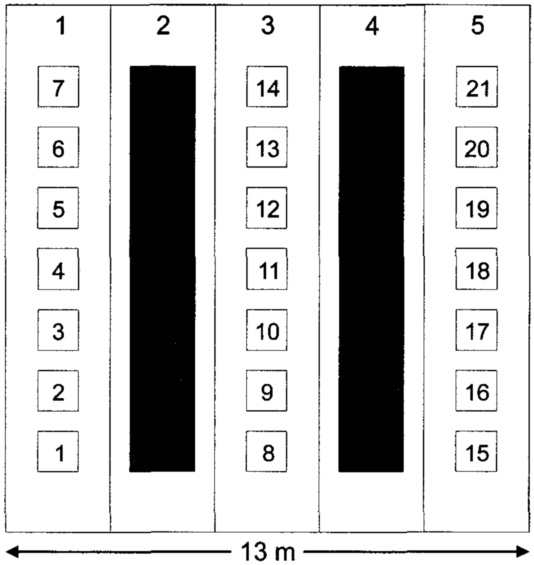

Figure 1. Plot infrastructure at Flakkebjerg with five subplots and 21 mini-plots. The harvested plots are shown in a dark tone.

Results and discussion

The average yields of the cereal and pulse crops in 1997 are shown in Table 3 for each site and for the two fertilizer levels, separately. As 1997 was the first year of the experiment, there were no residual effects of the other experimental treatments (crop rotation and catch crop). The yields of the spring cereals were surprisingly identical across the sites, and there was a clear fertilizer response at all sites. Winter wheat yielded considerably lower on the sandy soil (Jyndevad) than on the other sites. There were only minor differences among sites in yield of the peas/barley mixture, and the yield of this crop mixture was comparable to the yield of the fertilized spring cereal crops.

The yields were compared with the standard yields used for fertilizer planning in conventional farming on the respective soil types and climate regions (Plantedirektoratet, 1997). This gave the following ranking of fertilized yields in the experiment as a percentage of standard conventional yield for the respective crops: winter wheat (52%), spring oat (76%), spring barley (79%) and peas/barley (92%).

The experimental area at Foulum had a varying cropping history in the different blocks and split-plots of the experiment. The main difference was the number of years since a grass or grass-clover ley had been ploughed-in. This varied from two to more than five years with a corresponding variability in soil fertility. There was a considerable yield response to this cropping history (Table 4). There was almost no difference in total yield of the peas/barley crop with change in cropping history, but the percentage of peas in the yield changed from 63% in the high fertility plots to 90% in the low fertility plots. The strongest response of cropping history to yield in the cereals was observed in winter wheat and the smallest response in spring oat.

As illustrated in Figure 2a, there was complementarity in the yield of the two components in the peas/barley mixture. The pea crop, however, failed to establish properly in one of the plots at Jyndevad, and in this case the spring barley crop could not make-up for the yield loss from the pea crop. It is thus mainly the pea crop that is able to compensate for low soil fertility. Similar results are found in other cereal/pulse mixtures (Ofori & Stern, 1987).

An increasing fraction of cereals in the crop rotation will presumably increase problems with nitrogen supply and weed control. These problems are assumed to occur on the sandy soils first. Increased recycling of nitrogen in the systems will increase nitrogen supply to the crops, but at the same time the use of catch crops offers less possibilities of mechanical weed control. The use of nitrogen fixing catch crops or the use of cereal-clover bi-cropping may provide additional nitrogen input in arable crop rotations for grain production. Grain yield in winter wheat bi-cropped with clover has been quite variable and only about 50% of conventional yields (Clements *et al.*, 1997). No proper method for managing the clover/wheat competition has, however, previously been applied.

Table 3. Grain and seed yields (t ha^{-1}) at the different experimental sites in 1997 with and without fertilizer.

Crop	Location	No slurry	Slurry
Spring barley	Jyndevad	3.08	3.80
	Foulum	3.56	4.60
	Flakkebjerg	2.20	4.19
	Holeby		4.66
Spring oat	Foulum	2.88	3.85
	Flakkebjerg	2.15	3.86
	Holeby		3.67
Winter wheat	Jyndevad	1.66	2.88
	Foulum	2.75	4.41
	Flakkebjerg	2.92	4.20
	Holeby		5.01
Peas/barley	Jyndevad	3.96	-
	Foulum	4.31	-
	Flakkebjerg	3.65	-
	Holeby	4.54	-

Table 4. Grain and seed yields (t ha^{-1}) at Foulum in 1997 with and without fertilizer for different cropping histories represented as number of years following a grass or grass-clover crop.

No years	Spring barley		Spring oat		Winter wheat		Peas/barley
after grass	No slurry	Slurry	No slurry	Slurry	No slurry	Slurry	No slurry
2	4.80	5.48	3.20	4.81	3.94	5.17	4.73
3	2.53	4.96	2.46	3.35	2.75	4.99	4.04
>5	2.12	3.01	2.67	3.86	1.32	2.58	4.07

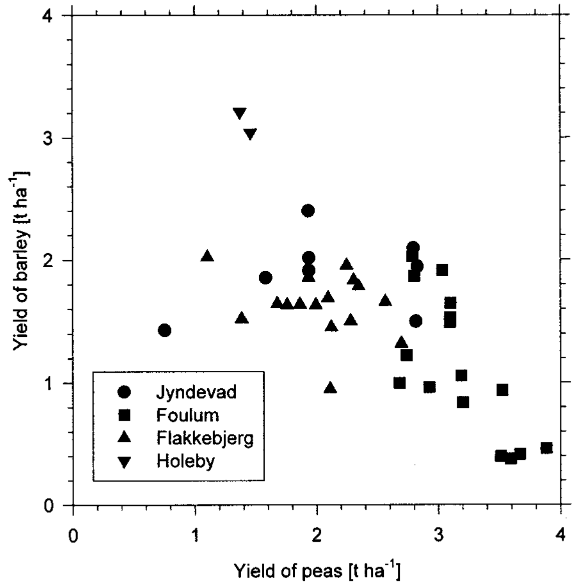

Figure 2. Seed yield of peas plotted versus grain yield of spring barley for each plot of the peas/barley mixtures in 1997.

It is difficult to estimate the effects of the yield-limiting factors in these systems, as they are influenced by many interactions and because there will be an evolution over time. Bulson *et al.* (1997) thus found different trends in winter wheat yields in different four-year crop rotations in England. The mini-plots in the large experimental plots may be used for conducting small experiments to clarify some of the reasons behind and the magnitudes of the different yield-limiting factors.

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Weed community composition in a mixed farming system in Central Italy[1]

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Introduction

Environmental problems often posed by conventional agriculture require a reappraisal of cultural practices towards enhanced sustainability of agricultural systems. Sustainability can be enhanced by appropriately integrating crop rotation, intercropping and animal husbandry into a mixed farming system to allow more internal transfer of energy-matter among its components and to reduce reliance on external inputs (Caporali & Onnis, 1992). In a real farm situation, adoption of mixed farming systems requires a period of transition from conventional to mixed farming. From an agronomic standpoint, this period should serve the purpose of adjusting cultural practices which will be subsequently implemented in the mixed farming system in order to enhance crop and system performance. In this context, it is particularly important to look at the evolution of weed communities. Weeds may pose a serious threat to the performance of a mixed system, by decreasing crop yield and reducing forage palatability. Clark (1998) observed that in organic systems, weeds were the most serious problem because they were costly to manage and escaped control in several years. However, a system based on a high diversification of agronomic practices should theoretically lead to an increase in biodiversity, which in turn should maintain weed pressure below the damage threshold (Altieri, 1995).

The aim of this study was to evaluate the effects of crop sequence, durum wheat (*Triticum durum* Desf) cultivar and organic fertilization on entity and composition of weed communities in an innovative cropping system chosen as the base for a mixed farming system.

Material and methods

Farm, system and trial description

The experiment is taking place on a 402 ha-large farm located at Bomarzo, in the upper valley of the river Tevere (Central Italy). The farm is composed of two separate entities, one of which (70 ha) is run as a conventional farming system and the other (332 ha) as an organic farming system, according to the principles of EU Reg. No. 2092/91. The organic part of the farm is composed of 35 ha of vineyard, 37 ha of hazel grove, 100 ha of woodland and 160 ha of cropland. At present, nearly the whole conventional cropland is cultivated with durum wheat monoculture, while the organic cropland is mostly sown with

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either sunflower (*Helianthus annuus* L.) or durum wheat, cultivated in a 2-year rotation. About 10% of organically-grown durum wheat is intercropped with subterranean clover (*Trifolium subterraneum* L.). In autumn and winter following wheat harvest, the land is hired by local shepherds whose flocks graze on both forage originating from re-seeded clover and plants emerging from wheat stubble. The organic crops are fertilized with poultry manure obtained by mixing home-grown wheat straw with chicken slurry coming from nearby poultry farms.

At present, the organic part of the farm is in transition between a specialized and a mixed system. In late 1997, the farm owner purchased a 150-head sheep flock, supposed to expand to 1000 heads in the coming years. From autumn 1998 onwards, those sheep will graze on part of the land presently rented to local shepherds, thereby originating a self-sustained mixed farming system. This system will be based upon an innovative cropping system particularly suited to a Mediterranean environment (2-year rotation between a durum wheat/subterranean clover intercropping and sunflower), which has been introduced in the organic part of the farm. In this cropping system, subterranean clover operates as a living mulch in the cereal, as a cover/forage crop following durum wheat harvest and clover re-seeding and as a green manure for the subsequent sunflower crop (Caporali *et al.,* 1993).

Since 1995, this cropping system has been examined at farm level in an experimental trial where three durum wheat cultivars are factorially combined with three types of fertilization after a sequence of annual crops or a 5-year lucerne ley. The trial has been arranged in a split-plot layout with durum wheat cultivars in the main plots, fertilization types in the subplots and crop preceding sequence as a third, non-randomized factor including the other two. Subplot size is 576 m^2 (80 m length × 7.2 m width). Durum wheat cvs Appulo, Arcangelo and Daunia are intercropped with subterranean clover cv. Mount Barker in paired alternated rows (2 wheat rows followed by 2 clover rows), spaced 12.5 cm apart. Seeding rates are 500 seeds m^{-2} for durum wheat and 25 kg ha^{-1} of seed for clover. The fertilization treatments include (*i*) Poultry Manure (10 t ha^{-1}, containing 280 kg total N) incorporated at 40 cm depth by means of a mouldboard plough (PM40), (*ii*) Poultry Manure (10 t ha^{-1}, containing 280 kg total N) incorporated at 15 cm by means of a disk harrow (PM15) and (*iii*) control (no fertilization, ploughed at 40 cm depth). The same fertilization treatments are applied prior to the subsequent sunflower crop. Sunflower cv. Romsun HS 90 has been sown in rows spaced 50 cm apart at a seeding rate of 6.5 seeds m^{-2}. Weed control in durum wheat relies on the competitive effect exerted by the clover mulch. No direct weed control is presently scheduled in sunflower.

Weed sampling and statistical analysis

Entity and composition of weed communities were determined at durum wheat tillering stage and harvest (1996) and at sunflower harvest (1997). Weeds were counted by species in seven 10 m-long transects per plot except at wheat tillering stage, when weed densities were pooled as dicots, grasses and total weed densities. Weed biomass by species was sampled only at crop harvest in a 1 m^2 quadrat per transect. Total weed density and biomass data were subjected to ANOVA, after transformation as $\sqrt{(x+0.5)}$ when deemed necessary.

Treatment means were compared by a Fisher LSD protected test at $P \leq 0.05$. Composition of weed communities was analysed by means of canonical discriminant analysis by taking each weed species as a variable. This multivariate analysis procedure may highlight both significant differences between treatments based upon their weed community composition and characteristic associations between weed species and treatments (Bàrberi *et al.,* 1997). The 18 treatment centroids (means) were plotted in an ordination diagram where the axes represent the first two canonical variables. Differences among treatments were tested by an F-test performed on pairwise Mahalanobis squared distance between treatment centroids. Weed species (original variables) that had a coefficient of correlation with the first and/or the second canonical variable > 0.4 were represented in a biplot, constructed by superimposing a vector diagram (vectors = species) on the ordination diagram. In Figure 1, points represent treatment centroids, plotted on the first (−3÷3 or −12÷12) scale, and vectors show the correlation between weed species and canonical variables, read on the second (−1÷1) scale. Vectors were drawn by connecting the origin with a point whose coordinates are given in the correlation matrix. The direction of the vector indicates the type of association between weed species and treatments, which is higher when a vector points towards a centroid. The strength of the association is proportional to the vector length.

Results and discussion

Total weed density and biomass

Total weed density in durum wheat was overall limited and influenced only by fertilization type. At crop tillering stage, total weed density in the non-fertilized treatment was nearly double that in PM15, while the value of PM40 was in-between (Table 1). At harvest, total weed density was highest in the non-fertilized treatment and lowest in PM40. Total weed biomass was generally low and did not vary among treatments (average value = 11.1 g m^{-2}). This result is mainly the result of the subterranean clover living mulch, whose weed suppressing potential has also been pointed out by Ilnicki & Enache (1992).

In the subsequent sunflower crop, total weed density at harvest varied according to preceding crop sequence, durum wheat cultivar and fertilization type, although interactions among experimental factors were never significant (Table 2). Sunflower had higher weed densities following annual crops than following lucerne ley. Compared to cv. Appulo, total weed density of sunflower which followed cvs Arcangelo and Daunia was 52% and 78%

Table 1. Effect of type of fertilization on total weed density (plants m^{-2}) at tillering stage and harvest of durum wheat in 1996.

Type of fertilization	Tillering stage	Harvest
Absent	16.2 a	1.5 a
Poultry manure incorporated at 15 cm	8.7 b	1.1 ab
Poultry manure incorporated at 40 cm	12.6 ab	0.7 b

Within each column, values followed by the same letter are not significantly different according to a Fisher LSD protected test at $P \leq 0.05$.

lower, respectively. Moreover, weed density was about 30% higher in PM40 than in PM15 or in the non-fertilized treatment. Despite a relatively low density, total weed biomass at sunflower harvest was generally high, and varied between fertilization regimes, depending on the durum wheat cultivar that preceded sunflower (Table 3). Weed biomass did not vary significantly across fertilization treatments after cvs Arcangelo and Daunia; in contrast, when sunflower followed durum wheat cv. Appulo, the weed infestation was more severe in PM40 than in PM15 (+129%) or in the absence of fertilization (+72%). Weed growth in sunflower seemed particularly stimulated by deep manure incorporation. Overall, high weed biomass observed at the end of the crop cycle suggests adoption of direct mechanical weed control in the years to come to limit weed infestation.

Weed communities composition

Better results of canonical discriminant analysis (i.e. higher percentage of total variance explained by the first two canonical variables) were obtained in the density-based analysis for durum wheat and in the biomass-based analysis for sunflower; as a consequence, only the latter two biplots are shown in Figure 1.

Table 2. Total weed density (plants m^{-2}) at sunflower harvest in 1997. Mean effects.

Preceding crop sequence	
Annual crops	14.8 a
5-year lucerne ley	5.6 b
Preceding durum wheat cultivar	
Appulo	13.2 a
Arcangelo	8.7 b
Daunia	7.4 b
Type of fertilization	
Absent	8.4 b
Poultry manure incorporated at 15 cm	8.8 b
Poultry manure incorporated at 40 cm	11.8 a

Within each effect, values followed by the same letter are not significantly different according to a Fisher LSD protected test at P≤0.05.

Table 3. Total weed biomass (g m^{-2}) at sunflower harvest in 1997. Preceding durum wheat cultivar × type of fertilization interaction.

Type of fertilization	Preceding durum wheat cultivar		
	Appulo	Arcangelo	Daunia
Absent	516.2 bc	314.8 c	493.2 bc
Poultry manure incorporated at 15 cm	387.5 bc	455.6 bc	477.7 bc
Poultry manure incorporated at 40 cm	888.3 a	389.8 bc	538.3 b

Values followed by the same letter are not significantly different according to a Fisher LSD protected test at P≤0.05.

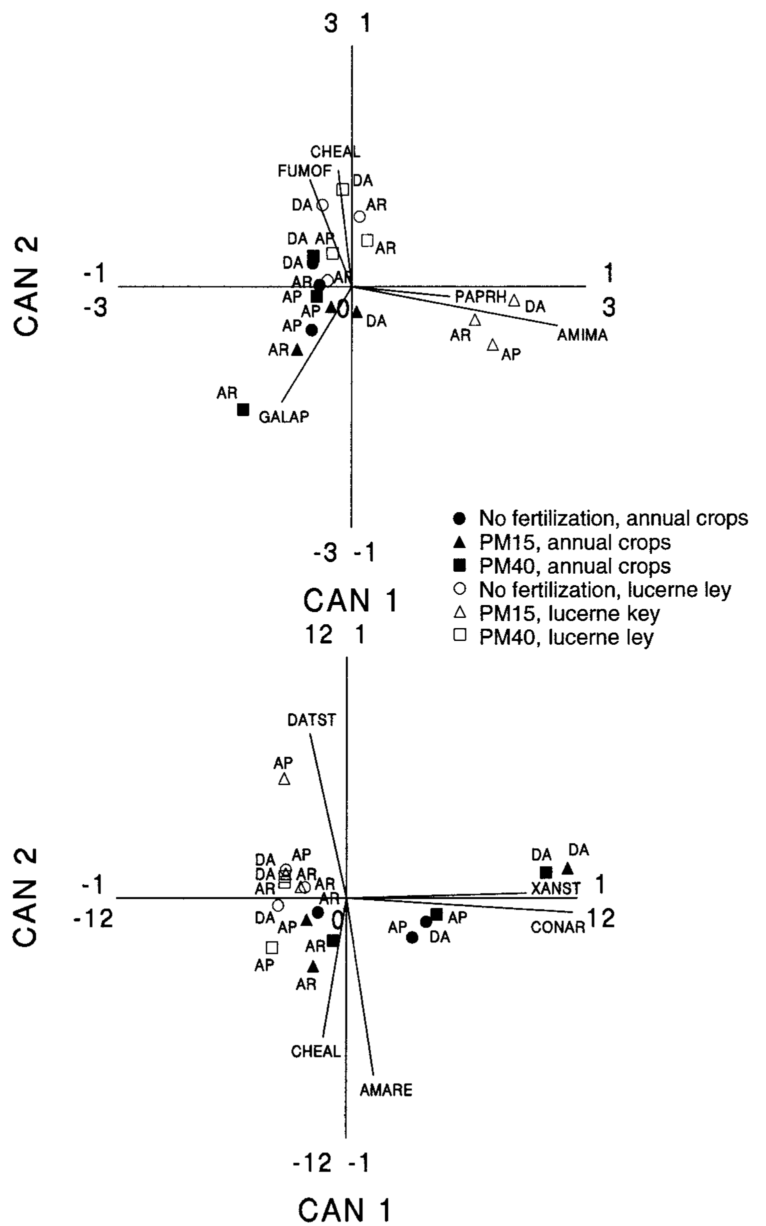

Figure 1. Biplot of weed communities at harvest in durum wheat (top) and sunflower (bottom). CAN 1, CAN 2, first and second canonical variable, resp.; PM15 and PM40, poultry manure incorporated at 15 and 40 cm, resp.; AP, durum wheat Appulo; AR, durum wheat Arcangelo; DA, durum wheat Daunia; AMARE, *Amaranthus retroflexus* L.; AMIMA, *Ammi majus* L.; CHEAL, *Chenopodium album* L.; CONAR, *Convolvulus arvensis* L.; DATST, *Datura stramonium* L.; FUMOF, *Fumaria officinalis* L.; GALAP, *Galium aparine* L.; PAPRH, *Papaver rhoeas* L.; XANST, *Xanthium strumarium* L. See also text.

A tendency towards differentiation among weed communities based mainly on preceding crop sequences was observed in durum wheat (Figure 1), although the overall diversity in weed communities was somewhat poor - as indicated by the limited range in axes values – because of low weed density. The first two canonical variables explained 90.3% of the total variance, thus providing a valuable basis for the interpretation of data. Within the same preceding crop sequence, significant pairwise differences between treatments were more common after lucerne ley than after annual crops (data not shown). In the former group, shallow incorporation of poultry manure, regardless of the durum wheat cultivar, resulted in weed communities different from those in all the other treatments and characterized by the presence of *Ammi majus* L. and – to a lesser extent – *Papaver rhoeas* L. Two other weed species, i.e. *Chenopodium album* L. and *Fumaria officinalis* L. were associated with the lucerne ley precession, while *Galium aparine* L. was the only species significantly associated with the annual crops precession.

In sunflower (Figure 1), the first two canonical variables explained 85.3% of the total variance. High weed biomass at crop harvest resulted in weed communities generally more differentiated than in durum wheat (see range of axes values). Similarly to what was observed in durum wheat, weed communities seemed to differentiate mostly according to preceding crop sequence. However, in contrast with durum wheat, weed communities in sunflower were more variable (i.e. sparse in the ordination diagram) within the lucerne ley than within the annual crops sequence. In the latter group, weed flora composition was not independent of the durum wheat cultivar grown prior to sunflower, since weed communities following cvs Daunia and Appulo, irrespective of fertilization, were different from the others and were strongly characterized by the presence of *Convolvulus arvensis* L. and *Xanthium strumarium* L. *Amaranthus retroflexus* L. and *C. album* were also associated with the precession of annual crops; in contrast, *Datura stramonium* L. typically appeared in sunflower following the lucerne ley.

Interpretation of weed community composition should be cautious, since the trial has begun recently. However, each of the experimental factors suggests influence on the weed flora spectrum. In this respect, crops following a sequence of annual crops seem to have a potentially more troublesome (i.e. competitive) weed flora (e.g. *G. aparine* in durum wheat, *A. retroflexus* and *X. strumarium* in sunflower). Differences across years in poultry manure composition and grazing activity are also likely to cause shifts (often unpredictable) in weed communities. As a consequence, flexible integrated weed management strategies have to be developed and implemented in a mixed farming system. For example, management of sheep grazing intensity (Popay & Field, 1996) may be a useful additional weed control means to be checked in the system.

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The effect of crop rotation on nitrogen fertilizer input for wheat

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Introduction

In Mediterranean regions, the recovery of fertilizer nitrogen (N) by wheat is, in general, low. For the southern regions of Portugal a review of records from a large number of trials with wheat indicates values varying from 20 to 40% (Alves, 1979). There are several reasons for this low efficiency (Carvalho & Basch, 1996). In the first place, excess of rainfall during the winter time (3/4 to 4/5 of the total annual rainfall occurs from November to February) creates conditions for leaching losses (Seligman & Van Keulen, 1989). Secondly, the winter temperatures in these regions are high enough for a continuous development and growth of the cereals. During this period important yield components are established, like the number of tillers and the number of spikelets per ear, and any N deficiency during this period will result in a yield reduction (Carvalho, 1987). Due to a generally low organic matter content of the soils in the region (1% or even less), the N demand of the crop can only be satisfied if mineral N is applied during winter.

A possible way of reducing the need for N fertilization in cereals in the Mediterranean regions could be the use of legumes as preceding crops. The potential of N incorporation in the soil by the legume-rhizobium association is very high, but it can present a large variation in dependence of the conditions (Nutmann, 1976), and in reality N_2-fixation rates often range only between 10 to 15% of their potential (Harris, 1988). The presence of an efficient rhizobium strain and the vigour of the crop play an important role (Alves, 1979) and due to the irregularity of precipitation in the Mediterranean climate there is a considerable variation among years regarding total biomass production of the legume. The type of legume is also very important. Forage legumes tend to fix more N and leave a larger proportion of that N in the soil as compared to grain legumes (Lynch & Wood, 1988). The management of the forage crops also plays a decisive role: grazing returns more N to the soil than cutting for hay or silage (Williams *et al.*, 1960). In addition to the amount of N fixed and left in the soil by the symbiotic association, the benefit for the following crop also depends on the recovery rate of that N. This rate is affected by the N mineralized and accumulated in the soil, prior to and during the leaching period, and the uptake by the crop. The mineralization rate depends on the various environmental factors that govern microbial activity, temperature having a major effect. Under Mediterranean conditions, where the average temperature during fall and winter is relatively high, the potential for mineralization and N leaching losses during the wet season is very high and the amount of N recovered by a wheat crop after a legume can be considerably low (Alves, 1961).

To test the potential of legume crops as nitrogen suppliers to the following wheat crop, within the context of mixed farming systems, a two-year crop rotation trial was initiated.

Material and methods

Preceding crops Six legumes were tested as N suppliers. Three of them were forage legumes (red clover, Persian clover, annual medics) and the others pulses (winter varieties of chick-pea, faba bean and peas). Sunflower was used as a reference crop, as it is one of the most common preceding crops for wheat in Portugal.

The forage legumes, grain legumes and the sunflower crop were sown in October, November and March, respectively, during the seasons 1991-92 to 1994-95. The wheat crop was sown in November of 1992-93 to 1995-96. Of the forage legumes, half of the produced biomass was returned to the soil, to stimulate the recycling of nutrients by animal grazing. For the grain legumes and sunflower all plant residues were left on the soil.

Nitrogen levels for wheat 0; 60; 120; 180 kg N ha^{-1}.

Experimental design The experimental design was a complete randomized block for the preceding crop with a split-plot for nitrogen levels.

Parameters measured Soil samples were collected at the beginning and end of the season for determination of the values of organic matter, total N and mineral N. Nitrogen uptake by the crop and its amount left by the crop residues were measured at the end of the season.

Results and discussion

Table 1 presents the relative effects of the preceding crop on total N in the soil (0-60 cm) at seeding of the following wheat crop (November). On average over the four years, considerable quantities of the total N content in the soil could be detected. The forage legumes, in comparison with sunflower, increased total N content to 55.5 g N m^{-2}. The grain legumes increased total N to 25.3 g N m^{-2} in comparison to sunflower, which means that the forage legumes introduced 30.2 g N m^{-2} more compared to the grain legumes.

Table 1. Effect of the preceding crop on the total soil N (0-60 cm), at seeding of the wheat crop (November).

	Difference in total soil N (g m^{-2})
Between forage legumes and sunflower	+55.5
Between grain legumes and sunflower	+25.3
Between forage and grain legumes	+30.2

Table 2. Effect of the preceding crop on the mineral soil nitrogen (0-60 cm), at seeding of the wheat crop (November).

	Mineral N in the soil (g m^{-2})
Sunflower	5.5
Grain legumes	8.2
Forage legumes	8.0

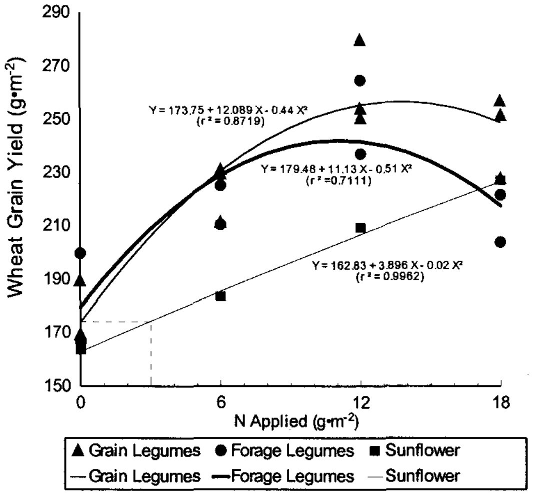

Figure 1. Wheat response to mineral N fertilization after three different preceding crops. Average of four years.

These values are in accordance with results obtained by other authors (Lynch & Wood, 1988). However, in terms of soil mineral N for the same period and treatment (Table 2), there was no difference between the two types of legumes, and the benefit of the legumes in relation to sunflower was about 3.0 g N m^{-2}.

With regard to wheat grain yield, the results for the average of the four years (Figure 1) are consistent with those related to soil mineral N (Table 2). Wheat grain yield without any nitrogen fertilization was almost the same after the two types of legumes (grain and forage), and about 3.0 g N m^{-2} had to be applied after sunflower to achieve the same grain yield than after the legumes without N fertilization. However, wheat grain yield and crop response to N were very much affected by water availability since three out of four years of the trial period were very dry. The season of 1994-95 was the driest (total precipitation of 282 mm) and the only wet season was 1995-96 (total precipitation of 869 mm).

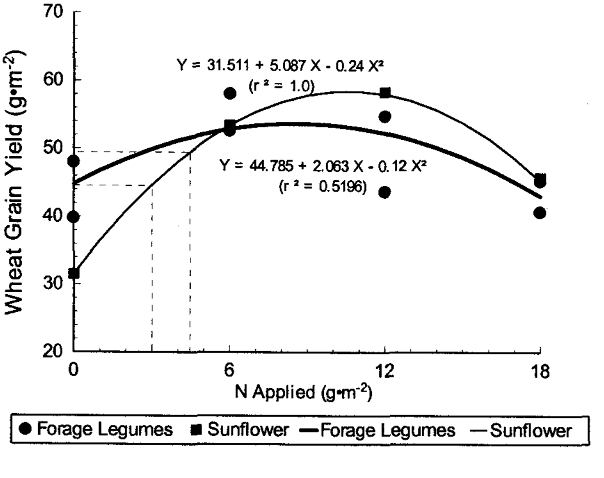

Figure 2. Wheat response to mineral N fertilization after forage legumes and sunflower during the season of 1994-95 (dry year).

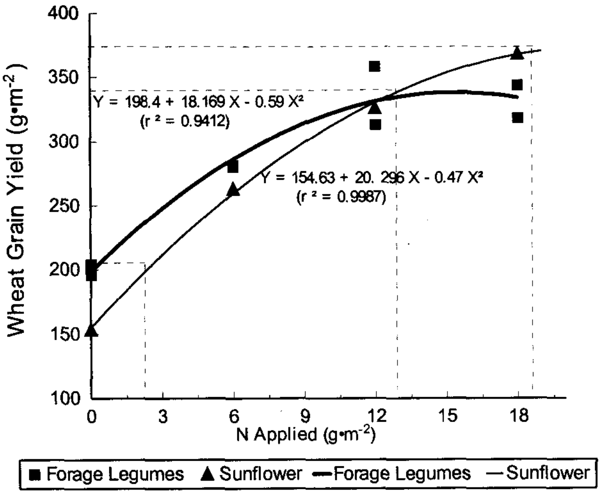

Figure 3. Wheat response to mineral N fertilization after forage legumes and sunflower during the season of 1995-96 (wet year).

For the season 1994-95 (Figure 2), the response of the wheat crop to N was quite small, due to water stress during the reproductive stages of the crop. The wheat response to N after the forage legume was even so small that in economic terms, regarding a grain/N ratio of 3/1, there was no need for N application. The response of the wheat crop to N fertilization after sunflower was more pronounced. The most economic level was 4.3 g N m^{-2}, achieving a wheat grain yield of 49.1 g m^{-2}, and around 3.0 g m^{-2} of nitrogen would have been necessary to achieve the same yield than after the forage legume without nitrogen.

For the 1995-96 season, wheat response to nitrogen was much higher (Figure 3). When no N was applied, grain yield of the wheat after the forage legumes was 43.8 g m^{-2} higher than after sunflower and 2.3 g N m^{-2} would have been necessary to apply to achieve the same yield. The most economic levels of N were 12.9 and 18.4 g m^{-2} after the forage legumes and sunflower, respectively. The corresponding expected yield would have been 336 and 369 g m^{-2} of grain. The grain/nitrogen ratio would have been higher for the wheat after forage (336:12.9=26) than after the wheat following sunflower (369:18.4=20), if the most economic N rate would have been applied to both. However, the higher N rate applied to wheat after sunflower would have had an economical return. An additional amount of 5.5 g N m^{-2} was required to increase the yield with 33 g m^{-2}, which means 6 g of grain per g of extra nitrogen. The better response of wheat after sunflower to higher levels of N was probably due to better weed control during the wheat after sunflower than after forage.

Conclusions

In summary, legumes can accumulate large amounts of N in the soil, forage legumes being more effective than grain legumes. However, in terms of mineral N at seeding time of the wheat, there were no differences between the two types of legumes and the benefit in relation to sunflower was around 2.8 g N m^{-2}. Although the wheat response to N was very much affected by precipitation (Seligman & Van Keulen, 1989), between 2.3 to 3 g N m^{-2}

were necessary to apply for the wheat after sunflower to achieve the same yield as after the forage legumes without nitrogen. This suggests that the efficiency of the recovery by the wheat crop, of the nitrogen accumulated in the soil by the legumes, is very low. From an economic point of view there is a difference between dry and wet years. In dry years, wheat did not respond to N after the forage legume. After sunflower, the most economical N level was then 4 g N m^{-2}. However, this application level was not economical compared to unfertilized wheat after the forage legumes, since it provided only an extra grain yield of 4.3 g m^{-2}. In the wet year, the most economic N level was 5.5 g N m^{-2} higher for the wheat after sunflower as compared to the forage legumes. However, the achieved yield for this level of N was 33 g m^{-2} higher, which still provides a net return. From an environmental point of view, the advantage of the legumes as preceding crops is also questionable, once the reduction of nitrogen input to the following wheat crop is much less than the nitrogen input to the soil, suggesting that there is a higher potential for nitrogen leaching losses.

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A comparison between organic and conventional farming systems with respect to earthworm biomass and its effects

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Introduction

Over the past 30-40 years, intensive farming using chemical fertilizers, herbicides and pesticides has been so widespread in the more productive agricultural areas of Britain that the term 'conventional' now describes it. With the common practice of conventional farming, the benefit of earthworms to soil fertility is probably not fully appreciated. However, the threat of non-indigenous flatworms to British earthworms and the recent appeal of sustainable farming has kindled new interest in earthworms and their relation to soil fertility. Earthworm populations are good biological indicators of soil fertility, because their activities play a role in the decomposition of organic matter and the release of nutrients, mix and aerate soil and create drainage channels.

Methods

The three pairs of organic and conventional farms selected represent a gradient from arable to mixed farming (Table 1). The organic and conventional pairs at each locality were selected on the basis of similar soils and crop rotations. However, crop rotations at each locality do not compare exactly due to intrinsic system differences and farmers' decisions. In any one locality, organic systems typically have proportionately longer periods of ley in rotation due to the need for fertility building. For this workshop, presented results will focus on the mixed farms.

Sampling was carried out at four replicate points per phase of rotation, three times over a crop year: autumn, spring and early summer. Earthworms were collected by handsorting blocks of soil (900 $cm^2 \times 25$ cm deep). Deep burrowing species below the blocks that were removed for handsorting were brought to the surface using 0.5 - 1.5 l of a weak (0.5%) formaldehyde solution. The actual quantity of formaldehyde depended on its infiltration rate. Earthworms were identified using the keys and descriptions of Sims & Gerard (1985).

Earthworm benefits were quantified by comparing microaggregate stability (Scullion, 1984), microbial biomass carbon (Vance *et al.*, 1987) and P and K concentrations (MAFF, 1986) of surface earthworm casts with the parent soil, and measuring rates of infiltration through earthworm burrows. Casts were collected from phases of rotation that were common between organic and conventional systems chiefly during autumn and spring when casting was most abundant.

Infiltration measurements were made using 40 cm diameter, falling-head, single infiltration rings (Logsdon *et al.*, 1993). Pairs of infiltration rings were sunk 3 cm into the

Table 1. Crop rotations and soil texture class for the farms selected for the study (O = organic; C = conventional).

Site	Farm	Location	Basic crop rotation (years cereal : ley)	Texture class
1	EFRC (O)	Berkshire	3 : 1 (stockless)	Sandy loam
1	Sutton Estate (C)	Berkshire	Continuous arable	Sandy loam
2	Rushall's Fm. (O)	Wiltshire	2-3 : 2	Silty clay
2	Falkner's Fm. (C)	Wiltshire	3 : 1-2	Silty clay
3	Eastbrook Fm. (O)	Wiltshire	2 : 3	Clay
3	Manor Fm. (C)	Wiltshire	2 : 2	Clay
3	Rectory Fm. (C)*	Wiltshire	4 : 3-4	Clay

* Due to changes in cropping system on the original conventional farm, an alternative was also used in the second year of the study.

soil surface and a water-tight seal was created by smearing the soil that was in contact with both the inside and outside of the rings. The number of earthworm burrows per ring was recorded. In the area of one of the rings the burrows were blocked by smearing the soil surface, which was possible because the soils were clayey. Then both rings were filled with 14 l of water and the rate of fall in water level over time was recorded. The difference in the fall of water levels between rings was attributed to the rate of infiltration through earthworm burrows.

Earthworm biomass data were compared by analysis of variance for phases of rotation, common between organic and conventional farms. Multiple regression analysis allowed identification of systems differences, taking into account data from all phases of rotation even though certain phases were not present in both systems.

Results and discussion

Since seasonal changes in earthworm biomass were small compared to differences between phases of rotation, means of the three sample occasions in each crop year are presented (Table 2). In 1995-96, earthworm biomass on the organic farms was generally higher than on the conventional farms in two of the three systems (sites 1 and 3, Table 2) studied, and this was attributed largely to the organic systems including a greater proportion of ley within rotations. Earthworm populations in permanent pasture were monitored to take into account seasonal fluctuations. Year two earthworm biomass was generally less than that in year one and this reflected the exceptionally prolonged dry weather over the periods of sampling (Table 2). For the stockless comparison which included a continuous arable conventional farm (site 1), differences between systems were found mainly in the first cereal after one year of red clover ley in the organic rotation (data not shown). The corresponding cereal on the conventional farm followed a break crop of oil seed rape or beans. The pair of mixed farms (site 2) where cropping regimes were very close over the sample periods showed no systems difference for total earthworm biomass in both crop years (data not shown).

Table 2. Summary of means and comparison by ANOVA of total earthworm biomass between Eastbrook Farm (organic) and its conventional neighbours for the first and second year samples.

Farm	System	Phase in rotation	Earthworm biomass (g m^{-2})	
			1995-96	1996-97
Eastbrook	Organic	first cereal	327**	60^{NS}
Manor	Conventional	first cereal	96	45
Eastbrook	Organic	second cereal	50^{NS}	203***
Manor	Conventional	second cereal	54	31
Eastbrook	Organic	first year of ley	ND	*78**
Manor / Rectory[a]	Conventional	first year of ley	40	*108*
Eastbrook	Organic	second year of ley	108**	ND
Manor	Conventional	second year of ley	46	ND
Eastbrook	Organic	third year of ley	ND	*92* ^{NS}
Manor / Rectory	Conventional	third year of ley	ND	*137*
Eastbrook	Organic	permanent grass	176	125
Manor	Conventional	permanent grass	150	83

[a] for the two conventional fields labelled Manor/Rectory, samples in year one were carried out on Manor Farm and those in year two on Rectory Farm.

ND, no data due to incomplete representation of the crop rotation.

Data in *italics* correspond to the means of the spring and summer sampling occasions only.

^{NS} $p > 0.05$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

The results for the systems comparison with the largest proportion of ley to cereal cropping in the organic rotation (site 3, Table 1) are somewhat complicated by the fact that it was necessary to use two conventional farms in the second sample year, because the original conventional farm abandoned its grass leys for spring cereals in 1997. The basic rotation on the alternative conventional farm (Rectory) had a longer crop rotation than the original conventional farm (Manor). Where Eastbrook organic farm was compared with the conventional farm with the four year rotation (Manor), earthworm biomass was generally superior on the organic farm but where it was compared with the conventional farm with eight years of rotation (Rectory), there was no statistical difference in total earthworm biomass between systems. Although the crop rotation on Rectory farm was approximately twice that of Manor farm, both farms had similar ratios of ley to cereal cropping.

It is generally appreciated that earthworms respond favourably to periods of stability, so the increase in earthworm biomass over the periods of ley was expected. Table 2 indicates that two years of ley was insufficient to allow earthworm biomass to recover to or near carrying capacity (maximum biomass for the site). The largest earthworm biomass was on Eastbrook organic farm in the first year cereal after four years of grass ley. The large biomass in this field decreased by about 40% as the rotation went through the second cereal but it still remained significantly higher than that in the other fields. The systems differences

Table 3. Differences in earthworm biomass (g m^{-2}) between organic and conventional farms by multiple regression. Organic matter (weight loss on ignition) in %; moisture content in %.

System: Eastbrook organic versus Manor conventional
The following multiple regression equation was derived:
earthworm biomass = $-16.7 - 1.82$ organic matter^{NS} + 1.31 moisture* − 7.28 system*
$R^2 = 31\%$ Significance of the regression equation: $p = 0.013$

^{NS} $p > 0.05$; * $p < 0.05$.

Table 4. Microbial biomass-C for the leys commencing their second year on Rushall's organic and Falkner's conventional farms.

Sample period	Farm	Material	Microbial biomass (mg C g^{-1} dry soil)
Mean (Nov. '95 + Apr. '96)	Organic	Casts	0.39^{*}
Mean (Nov. '95 + Apr. '96)	Conventional	Casts	0.65
Mean (Nov. '95 + Apr. '96)	Organic	Soil	0.2^{NS}
Mean (Nov. '95 + Apr. '96)	Conventional	Soil	0.25

^{NS} $p > 0.05$; * $p < 0.05$.

Table 5. Concentrations of available potassium and phosphorus. Casts and soil samples were collected from the second year leys on Rushall's organic farm and Falkner's conventional farm.

Sample period	Farm	Age of ley (years)	Material	Available K (mg g^{-1} dry soil)	Available P (µg g^{-1} dry soil)
Nov. '95	Organic	2	Casts	0.27^{**}	18.7^{**}
Nov. '95	Conventional	2	Casts	0.57	69.4
Nov. '95	Organic	2	Soil	0.17^{NS}	16.3^{NS}
Nov. '95	Conventional	2	Soil	0.20	21.5

^{NS} $p > 0.05$; ** $p < 0.01$.

between the two conventional farms (site 3, Table 1) suggest that a long rotation which includes 3-4 years of ley is more favourable for earthworm populations than a shorter rotation with the same ratio of cereals to ley. Perhaps, after approaching or reaching carrying capacity, earthworm populations are better able to recover after periods of cultivation when conditions to their survival are less favourable.

Multiple regression analysis that took into account all available phases of crop rotation showed a significant systems difference between Eastbrook and Manor farm (Table 3). The coding of the organic (0) and conventional farms (1) explains why the systems component of the multiple regression was negative.

Microbial biomass-C and concentrations of available P and K in casts were significantly and consistently greater in the conventional compared with the organic systems (Tables 4 and 5) although only data for 1-2 sample occasions have been shown here. In contrast, soil concentrations were similar. The higher nutrient concentrations in the conventional casts therefore reflect higher concentrations in the crop residues of the conventional farms. One would expect the nutrients in casts to disperse into the till layer and eventually for the conventional soil itself to show higher nutrient concentrations. It is likely, therefore, that the nutrients in surface casts are prone to loss through weathering and leaching.

Different species of earthworms have different feeding habitats. Time has not yet permitted an examination of the data for differences in species composition between systems. It is possible that the higher nutrient concentrations in conventional casts may be due to differences in species composition between systems. We intend to have data, before the presentation, which will indicate why conventional casts have a higher nutrient concentration.

Both clay and clay plus silt stability were much higher for cast material than for the parent soil, showing that earthworm casting contributes to the improvement of soil structure (Table 6). However, differences in clay and clay plus fine silt stability between organic and conventional farms were insignificant. Earlier work on water infiltration through earthworm burrows (Figure 1) indicates that the methodology has potential for assessing the significance of earthworm activities. Further work on infiltration measurements were undertaken this March but it has not been possible to process the data in time. A qualitative review of the results showed a large variability in infiltration over short distances masked the effects of earthworm burrows but large differences between cereal and ley phases of rotation were observed.

Table 6. Loss on ignition (LOI), clay and clay plus fine silt stability for casts and soil samples that were collected from the second year leys on Falkner's conventional and Rushall's organic farms.

Sample period	Farm	Material	LOI (%)	Clay stability (%)	Clay + Silt stability (%)
Apr. '96	Organic	Casts	23^{*}	89^{NS}	64^{NS}
Apr. '96	Conventional	Casts	31	87	64
Apr. '96	Organic	Soil	10^{NS}	74^{NS}	41^{NS}
Apr. '96	Conventional	Soil	13	70	44
Apr. '96	Mean	Casts	27^{***}	88^{***}	64^{***}
Apr. '96	Mean	Soil	12	72	43

$^{NS}\ p > 0.05$; $^{*}\ p < 0.05$; $^{**}\ p < 0.01$; $^{***}\ p < 0.001$.

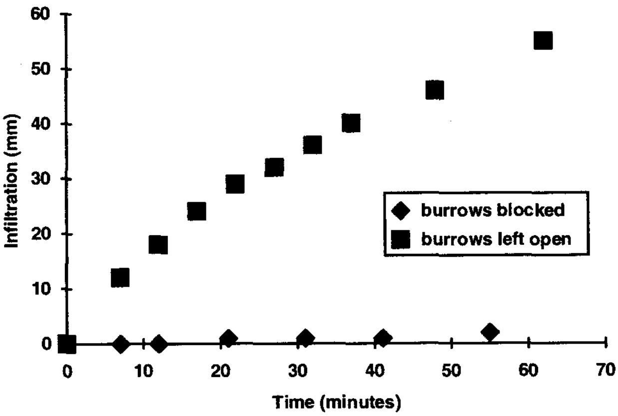

Figure 1. Cumulative infiltration with 267 surface burrows m^{-2}.

Conclusions

If earthworm biomass is the best biological indicator of soil fertility, we would recommend that a ley of four years has a significantly greater benefit than two years. Most farmers would not want to change their ratios of grass to cereals, so a rotation of 4 : 4 ley : cereal may be better for soil fertility than 2 : 2, because it gives the earthworm populations a chance to reach carrying capacity for part of the rotation. However, measures to optimize earthworm activities may not be appropriate for other farm requirements. For example, increasing the crop rotation may cause problems in weed control for organic farms. Further analyses of our data may indicate that components of the earthworm biomass, for example the abundance of the larger, deep burrowing species, are indicators of soil fertility than total biomass.

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A clover-cereal whole crop silage system for mixed farming

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Introduction

There is a pressing need to develop methods of growing cereals (either for grain or whole crop silage) that require much lower inputs of N fertilizer and other agrochemicals than current systems, but are economically viable and environmentally acceptable. Our work set out to achieve these aims.

Whole-crop silage

A system developed as part of an EU programme by IGER and IACR in the UK and partners in Ireland and Denmark allows growth of whole-crop silage in an environmentally benign way, that is well suited to mixed farming situations. The system that has evolved is straightforward and simple to adopt (Clements & Donaldson, 1997).

Initially, a sward of pure white clover is established, which is defoliated in autumn, either by machine and ensiled or grazed by sheep which return considerable amounts of nutrients via faeces and urine. The cereal is then direct drilled into the clover understorey which becomes permanent and perennial. There are some indications that increasing the seed rate from the normal 160-200 kg ha^{-1} by 30% may be beneficial.

In spring, there is a need to apply a small amount of nitrogen – around 50 kg ha^{-1}, or to apply slurry containing about that amount of mineral-N. The cereal and clover develop together and are cut as whole crop silage (i.e. at the soft dough stage of development of the cereal ear - usually in early July). The clover understorey recovers very quickly following harvest and is then cut and ensiled or grazed in autumn again and another winter cereal is direct drilled in to repeat the cycle. Following this system it has been possible to grow three or more successive winter wheat crops (Clements *et al.*, 1997).

The system is not suited to growing spring sown cereals – they are easily outcompeted by the clover. In early work, of the winter sown crops, barley tended to tiller too profusely and shaded the clover, as did winter oats which grow very tall. In much of our work, we used winter wheat cv. Hereward principally because of its disease resistance and the fact that it is a milling wheat which attracts a premium price. We have limited experience with other wheat varieties, but those tested, Ritmo and Terra, both performed reasonably well. We have used white clover cv. Donna in much of our work, but other cultivars were also well suited.

Cereal grain

Instead of being cut for silage, the crop can be left to develop so that the cereal matures and is harvested for grain. Clearly this is especially relevant for mixed farming situations. If taken for grain the cutter bar of the combine harvester needs to be raised to about 20 cm to avoid entanglement with the clover. The straw should be baled or removed by some other method, to reduce some cereal diseases in the next crop but also to facilitate direct drilling of the next wheat crop. The straw could be of considerable value in mixed farm enterprises, but if not needed, it could be chopped.

Advantages of the system

The need for nitrogen fertilizer is greatly reduced using this system and yields of silage exceeding 20 t ha^{-1} dry matter have been obtained. Slurry can also be utilized fully by the system and the presence of vegetation throughout the year reduces the risk of slurry running off the field surface.

The major pests in cereals are aphids which spread virus diseases. However, the need to use insecticides in the bi-cropping system is greatly reduced or obviated since aphid populations usually remain low. Firstly because of the changes in crop architecture and secondly due to the large build-up of populations of predatory beetles and spiders that occurs in the permanent perennial clover understorey.

Slugs damaged cereal seedlings in some instances, but were controlled by the use of metaldehyde. Some direct-drilling machines leave the slot into which the seed is placed open and this creates an ideal environment for slugs. However, some machines, e.g. Moore and Vaderstad Rapid, have a press wheat which closes the slot, making it less attractive to slugs and reduces the likelihood of damage by them.

Probably the most important foliar diseases of winter wheat are *Septoria* spp., which are splash-dispersed. The clover understorey however, deflects rain splash and greatly reduces the progress of this disease upwards on the plant. Fungicide is not usually needed to control Septoria in bi-cropped cereals, but if needed at all, half the dose rate suffices. Mildew (*Erisyphe*) is not usually a serious problem: both the low N status of the system and the inter-row buffering effect of the clover slow down disease development and allow, if required, half doses fungicide appear effective. Late season diseases such as rusts (*Puccinia*) have not been encountered due to varietal choice and season.

Late season lodging caused by eyespot (*Pseudocercosporella*) was a problem in the third successive wheat crop at one site, but only after the silage cut. Grain yield was markedly affected, but an unreplicated trial showed that this could have been prevented by the application of fungicide (cyproconazole and prochloraz) at half dose rate at growth stage 33. Soil borne diseases, e.g. take all (*Gaeumannomyces*), have not been a problem. In any case these stem based diseases could be obviated by switching to a break crop of oats in the third year.

The dense clover/cereal canopy makes it difficult for broad-leaved weeds to survive. However, grass weeds (*Poa* spp., particularly *P. trivialis*) have caused major losses. Fortunately, they were easy to control for the following year by applying paraquat, to which clover is resistant, in the autumn before drilling the cereal. The problem was site-specific and did not occur in all instances. Cleavers (*Galium*), particularly spreading from hedgerows, if allowed to encroach, could be a problem and may require chemical control (benazolin + 2,4,DB + MCPA).

Soil erosion and the associated problems of phosphate and particulate run-off into water courses are virtually eliminated by the bi-cropping system, because the perennial and dense plant cover retains its grip on the soil, year-round.

Earthworm populations build-up to high levels aided by the lack of soil disturbance, abundance of organic matter, the insulating effects of the permanent crop cover and low inputs of agrochemicals. Although there has been no scientific evaluation of the situation, the presence of large populations of earthworms together with the cover provided by bi-cropping probably enhances the survival of many wildlife species.

Results

Silage yields

The system is well suited to the production of whole crop silage especially on mixed farms where the option of leaving the crop to grow on for grain production would sometimes be very attractive. The area of whole-crop silage in Europe is increasing and not surprisingly, since its advantages include high dry matter yields of silage with a high dry matter content (means little effluent) and only one cut is needed which is out of phase with the major grass silage making period, thereby spreading the workload. Because inputs are low in the bi-cropping system, with little or no reduction in yield, gross margins are high – about twice those for conventionally grown crops in any particular year. As our experience with the system has increased yields of whole-crop silage have become more reliable and higher – about the same as for conventionally grown crops last year (1997) at the two main sites for example (Table 1).

The nutritive value of whole-crop silage grown in the bi-cropping system is also high. In one trial for example, the digestibility (DOMD) of the harvested crop was 61.2% compared with 64.5% for the conventional crop, with protein values of 6.9 and 7.5%, respectively.

Grain yields

Grain yields have been variable, and on occasions disappointingly low compared to conventional crops. However, at one site, North Wyke, last year (1997) the understorey was suppressed using a herbicide, which probably released a good deal of N and grain yields of the bi-cropping system were higher than for the conventional (Table 2).

Table 1. Yields of whole-crop silage (t dry matter ha^{-1}) at North Wyke and Long Ashton.

	Long Ashton				North Wyke		
	1994	1995	1996	1997	1995	1996	1997
Clover bi-crop	9.8	9.5	20.3	10.3	7.5*	11.8	8.1
Conventional	15.9	13.9	13.6	10.7	16.4	16.3	8.9

* Badly infested with grass weeds (*Poa*).

Table 2. Yield of cereal grain (t ha^{-1} @ 15% m.c.) at North Wyke and Long Ashton.

	Long Ashton				North Wyke		
	1994	1995	1996	1997	1995	1996	1997
Clover bi-crop	4.7	4.4	10.0[b]	4.0	2.0[a]	4.7	5.7[c]
Conventional	8.3	7.9	7.6[b]	5.0	8.6	9.0	4.1

[a] Badly infested with grass weeds (*Poa*).

[b] Clover in bi-cropped area ploughed and re-sown then drilled with wheat the first autumn. Conventional area was first wheat crop.

[c] Understorey suppressed by herbicide to release N.

Table 3. Comparison of inputs into bi-crop and conventional area.

	Bi-crop	Conventional
N fertilizer (kg ha^{-1})	50 (can be as slurry)	150-200
Insecticides (number of applications)	Nil	1 to 2 to control aphids
Fungicides (number of applications)	0.5 rate to control eyespot	2 to 3 to control range of diseases
Herbicides (number of applications)	Nil	1 to 2 to control various weeds

Inputs

Typically a conventional winter crop would receive 150-200 kg N ha^{-1} plus various applications of agrochemicals (Table 3). The inputs into bi-cropped crops are far less.

Future developmental work

Agronomic aspects of the system, at least as far as silage production is concerned are now well developed. There is scope to improve cereal yields further, without increasing inputs. Possibly this can be achieved by relatively minor adjustments to seed rates and row spacing. There is also a need to investigate the use of non-cereals to be used as break crops. There is considerable scope to develop the work for organic systems, and also potential to bi-crop other pairs of crops. For example soil erosion in maize could probably be prevented by growing it through an understorey of white clover.

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ON-FARM MIXED FARMING PROJECTS

Research and evaluation of mixed farming systems for ecological animal production in Denmark

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Introduction

Contrary to many conventional farming systems, organic farming has to rely on efficient nutrient circulation within the farm to maintain soil fertility and a high production. This means that in most cases mixed farming systems are the basic concept of organic farming. However, also between organic farms the degree of 'mixture' can be widely different, partly due to ideology, and partly because of pressure for economic reasons and from the market. On-farm studies represent an important method to communicate and evaluate the potential of new complex production systems. We have seen that the results from such studies have had a major impact on the development of this type of enterprises. Complex farm results can form the basis of the discussion among farmers interested in this form of production, as well as for the public and decision-makers whose interests may be markedly different from those of the farmers. Hence, there seems to be a need for concepts and tools to facilitate a discussion about overall efficiency and sustainability of different farming systems for milk, meat (veal and pork), egg and vegetable production. In this paper, some results are given from a long-term on-farm study of organic milk production and the concepts behind the establishment of an organic experimental station for livestock production.

On-farm study of organic milk production

During a period of 5 to 10 years, production, economic results, nutrient turnover, crop status and livestock health of 10 to 12 organic milk production systems were monitored. Production on individual farms was planned in cooperation between the farmer and the scientist visiting the farm approximately three times a year.

Data recording and presentation of the results served several purposes. However, to facilitate the general discussion on the farm and among advisors we developed the presentation form given in Table 1. The farm presented here has been run ecologically since 1987. This presentation gives the trend in production development as well as a 'balanced' evaluation of the production results in relation to indicators for technical productivity, environmental effects and economy.

The results calculated per milk producing unit (MPU, being one dairy cow with corresponding female young stock) and per kg energy corrected milk (ECM) are the most common expressions in conventional farming used to express the technical and economic efficiency, respectively. It can be argued, especially in organic farming, that the area available for a given animal production level is the limiting factor, when this area is defined

Table 1. Key figures for an organic milk production system (Jensen & Kristensen, 1998).

The last 5 years	1992-93	1993-94	1994-95	1995-96	1996-97
Milk, kg ECM per cow	7,328	7,544	7,399	7,564	7,544
Crops, SFU* per ha	4,344	5,160	5,050	4,905	4,308
Area, ha per cow	1.55	1.43	1.39	1.38	1.34
Theoretical self sufficiency, %	93	103	102	95	75
Total gross margin, DKK 1,000	1,023	1,282	1,204	1,274	1,087
Profits, DKK 1,000	440	711	672	637	475

Annual results of the farm 1996-97	Total	Per ha	Per MPU***	Per kg ECM
Production		(71.9 ha)	(53.6 pcs)	
- Milk, kg ECM delivered	374,997	5,216	6,996	-
- Crops, SFU*	309,778	4,308	5,779	0.83
Impact on environment				
- N-surplus, kg**	6,439	90	120	0.017
- P-surplus, kg	453	6	8	0.001
Economy				
- Gross margin, DKK	1,086,589	15,113	20,272	2.90
- Profits, DKK	475,285	6,610	8,867	1.27

* Scandinavian Feed Units (1 SFU = net feeding value of 1 kg barley).

** Calculated as given in Table 3.

*** Milk Producing Unit (1 MPU = 1 cow with corresponding female young stock for recruiting, normally 1 cow and 1.1 heifer).

as necessary for the crops as a basis for animal production. Furthermore, it is obvious to interpret the environmental effects per ha. The key figures in Table 1 show an organic system in good balance where milk yield and economic return are comparable to most conventional systems and where the environmental effects – expressed as N- and P-surpluses – are highly acceptable. Due to the inclusion of a relatively high proportion of grain (winter wheat and barley) in the crop rotation the N-surplus is lower than that of most organic milk production systems.

In Table 2, results from 12 organic farms are given for the growing season 1996-97. In general, the production level of the organic milk production systems seems fairly good. To a large extent the cows' diet can be based on the production of the grass-clover mixture, which is grown without N-fertilization. Furthermore, the grass-clover mixture allows production of an 'N-surplus' on the farm to be used for other crops. It appears that there is a considerable contribution from cash crops (grain crops and vegetables) in the systems and in certain cases this contribution is very high.

More detailed analyses, comparing organic with conventional production have shown that cow milk production differs by having a lower peak yield and a more flat lactation curve resulting in a 5% lower milk yield in the organic system (Kristensen & Kristensen, 1998).

Table 2. Annual results for 12 organic dairy farms 1996-97 (Jensen & Kristensen, 1998).

	Average	Minimum	Maximum
Milk-producing units (cows)	109	37	181
Per milk-producing unit			
Milk, kg ECM	7,077	5,800	8,800
Gross margin from livestock, DKK	15,752	10,042	17,947
Gross margin from cash crop, DKK	4,276	917	14,011
Profit, DKK	9,639	3,560	12,889
Per ha			
Milk-producing units	1.05	0.73	1.45
Crops, SFU	4,300	2,900	5,500
Milk, kg ECM	5,275	3,870	6,485
N-surplus*	118	88	154
P-surplus	7	2	23
Gross margin, DKK	15,709	11,888	26,273
Profit, DKK	6,829	4,224	11,173

* Calculated as given in Table 3.

Correspondingly, Halberg & Kristensen (1997) have found that crop yields were 20-35% lower for grain crops and 12-18% lower for fodder beets, grass and grass-clover mixtures.

From the farm studies and relevant experiments for organic livestock production, we have calculated an expected feed and nutrient turnover from different livestock systems. This calculation is intended to form the basis for the interpretation of results obtained on a newly established experimental farm for organic animal production.

Different systems for ecological animal production

In formulating an organic pig production system, it is much more difficult to match nutrient requirements of the pigs with relatively high yielding crops compared to organic milk production. It is a working hypothesis that mixing milk and pig production systems allows a better overall level of production than the two enterprises separately. Therefore, a newly established organic experimental farm was set up with three different crop rotations, as the basis for three different production units, i.e.:

- A cattle unit with 60% grass-clover mixtures in the crop rotation (3 out of 5 fields), a stocking rate of 1.1 animal unit per ha and an import of 10% of feeds (net energy basis) into the system.
- A pork unit with 20% grass-clover mixtures in the crop rotation (1 out of 5 fields), a stocking rate of 0.7 animal unit per ha and an import of 25% of feeds into the system.
- A mixed cattle and pork unit with 40% grass-clover mixtures in the crop rotation, a stocking rate of 1.1 animal unit per ha and an import of 15% of feeds into the system.

An 'animal unit' is an expression for the animal density on the land and represents in Denmark the load of either 1 adult cow (500-600 kg) or 3 heifers or 1 sow with connected 20 produced slaughter pigs per year.

The crop rotation and livestock production system were planned to simulate an 'intensive' organic milk production system with a high production level, an intensive pig production system and a mixed production system, respectively. In the latter, it was planned mainly to feed the cattle fresh grass and grass silage, with very small amounts of supplements, thus leaving the grain for the pigs.

Table 3. Results of model calculations on production and N-balances of different farming systems (after Kristensen & Kristensen, 1997). Total figures for dairy and pig herds are given in parentheses.

System		Dairy	Pig	Dairy + Pig (mixed)	
Grass-clover, %		60	20	40	
Import of animal manure, kg N ha^{-1}		0	45	0	
Herd - cows/sows ha^{-1}		0.81/0	0/0.71	0.44/0.45	
Feed					
- SFU ha^{-1} produced		5,298	3,201	4,836	
- SFU ha^{-1} imported		517	1,075	714	
Production					
Milk,	kg cow	7,357	-	6,286	
	kg ha^{-1}	5,980		2,772	
Meat	kg ha^{-1}	239	1,239	120/784	(904)
N-balance, kg ha^{-1}					
Input	Purchased feed	28	52	2/33	(35)
	Atmospheric deposition	21	21	21	
	Fixation	89	30	54/5	(60)
	Imported manure	0	45	0	
	Total	138	148	114	
Output	Milk	32	0	15	
	Meat	6	33	3/21	(24)
	Total	38	33	39	
Input – output		100	115	75	
Efficiencies					
N output/input		0.27	0.22	0.34	
N sold/N-surplus		0.38	0.29	0.51	

Kristensen & Kristensen (1997) have modelled this situation and some results are given in Table 3. The output is given as kg of product – milk and/or meat – per animal or per ha. Further the output from the system is given as N in animal products per hectare representing the amount of animal protein produced for human consumption. The model calculations indicate that the mixed dairy and pig system makes it possible to produce a higher amount of protein in animal products per ha (39 kg N) compared to the specialized dairy (38 kg N) or the pig system (33 kg N). Moreover, it seems that this system results in the smallest difference between N-input and N-output. In the long-term, it can be argued that this difference represents the potential loss of N to the environment. The better overall N-efficiency in the mixed system is primarily related to the better ability of this crop rotation to take advantage from the N left in the pre-crops, which means a lower risk for leaching/denitrification.

In the coming years, we shall investigate the major assumptions in the model calculations. However, even if these model results actually represent the reality, there are probably several technological and/or economic relations, that will counteract such a development. Nevertheless, there is a need to develop concepts and methodologies on the basis of which the results of such complex production systems could be evaluated with a broader view than only the economic aspects.

The next step in our on-farm research projects is to examine the potential of mixed farming systems in animal production where milk production is combined with pig or poultry production, or where pig production is combined with beef production or where cash crop (grain and seed) production is combined with cattle production.

In terms of financial returns and e.g. nutrient leakage from, or accumulation in, the system on a per hectare basis, it seems fairly straight to evaluate different systems. However, in terms of technical efficiency there is a pronounced need for better tools to evaluate the combined production of milk, meat and cash crops.

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Nitrogen flows in mixed farm systems in England: The Coates Farm study

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Introduction

There is an increasing need to minimize nitrogen (N) losses from farming systems. The EC Nitrate Directive, the Climate Change Convention on nitrous oxide emissions, and the likely EU and UNECE (United Nations Economic Commission for Europe) measures to control ammonia emissions provide aims and objectives for policy-makers. Most research aimed at decreasing losses of N has focused on plot or field-scale studies, and for either arable or livestock systems. Nitrogen losses from mixed farming systems and whole farms have received little attention. However, mixed farming systems are an important sector of the European agricultural economy, and the possibility of recycling N in organic manures more effectively within a single system makes them potentially more efficient than separate arable or livestock units. There is, therefore, a need to provide information on N cycling on mixed farms and generate management options for decreasing emissions while maintaining profitability.

Nitrogen flows are being investigated on a mixed farming system at Coates Manor Farm, owned by the Royal Agricultural College, Cirencester, Gloucestershire, UK, in a collaborative study with IACR-Rothamsted and IGER North Wyke. Nitrogen inputs, outputs and transfers are measured to identify key parts of the system where losses may occur. The aim is to define improved management strategies to encourage the optimum use of N and minimize losses to the environment.

The system

The 244 ha farm at Coates Manor is located on shallow clay-loam soil over limestone. It is a typical 'Cotswold' mixed farm, based on the current best management practices for this part of the UK. The farm has three enterprises: 160 Friesian Holstein dairy cows, 300 ewes and 120 ha of cereals. The system has a 7-year rotation. There are slight differences in the rotation from field to field. A rotation in one of the fields that can be described as typical for the farm is: grass ley - grass ley - grass ley - winter wheat - forage maize - winter wheat - winter barley. In addition, long leys and permanent pastures are grazed by the dairy herd, and by the sheep flock brought in from other College farms.

We have calculated an N budget and made detailed process studies for the whole farm as described below. However, in order to decrease the effect of soil variation on the process studies, ten small farmlets (120 m × 20 m) have been established. One farmlet was set out in each of ten fields in which the soil is the dominant (70% of the farm) Sherborne Series, a shallow stony clay loam (brown rendzina) of about 30 cm depth over limestone.

Material and methods

Farm records, field measurements, and established on-farm sampling and analytical techniques have been used to quantify N inputs, transfers and outputs. For inputs, samples of seed, fertilizers and feed were taken and analysed for total N by dry combustion on a Leco CN Analyser. For atmospheric deposition, N in precipitation and nitrogen dioxide were measured as described by Goulding *et al.* (1998). The deposition of other forms of N (nitric acid, particulates) was not quantified. Internal transfers such as those during grazing and manure spreading were estimated using grazing cages and the *N-CYCLE* model (Scholefield *et al.*, 1991) for the former, and manure sampling from 1 m × 1 m quadrates in the field for the latter.

Losses due to ammonia (NH_3) volatilization were estimated at 1 kg N ha^{-1} over cropping systems and 35% of the inorganic fertilizer applied over grazing systems (Rosswell & Paustian, 1984). This gives rather large emission factors from grazed areas and improved estimates from measured and tabulated UK emission factors will be used in future: some measurements of NH_3 losses from grazing animals have already been made and will continue. Leaching and denitrification losses and mineralization have been measured in the ten selected farmlets. Leaching losses were estimated using porous ceramic cups (Webster *et al.*, 1993). Ten suction cups were positioned at a depth of 60 cm in each of the farmlets. During the drainage season, samples were collected approximately every two weeks and analysed for nitrate-N and ammonium-N using a Tecator Flow Injection Analyzer. Nitrogen leached was calculated from the concentration of N in the drainage water and modelled drainage volumes calculated using the FAO Penman-Monteith evapotranspiration model (Smith *et al.,* 1991). Nitrogen mineralization rates were measured using a field incubation method (Hatch *et al.,* 1990); a similar, but shorter, incubation method with acetylene inhibition was used to determine denitrification rates. Both soil mineralization and denitrification measurements were made every two weeks for one twelve month period.

Results and discussion

The N budgets for Coates Farm for 1994-95, 1995-96 and 1996-97 are presented in Table 1. Those for the first two years are very dependent on estimates; we shall, therefore, concentrate on 1996-97. The dominant input is fertilizer, comprising 59% of the total, but feed (21%) and atmospheric deposition (14%) are also significant. Deposition near the dairy complex was almost twice (183%) that found elsewhere on the farm because of local NH_3 emission and re-deposition.

Of the N entering the system 35% was exported in saleable product, 36% of the N input was lost to the environment, and in 1996-97, 29% was unaccounted for. Such a large 'gap' is disappointing, but may be explained by some accumulation in soils and inadequacies in

Table 1. Nitrogen budgets for Coates Farm, 1994-97. Total for 244 ha.

	1994-95 (kg N)	1995-96 (kg N)	1996-97 (kg N)	1996-97 (%)
Inputs:				
Fertilizer	36398	33267	34530	58.5
Deposition*	8540	8553	8260	14.0
Seed	510	443	443	0.8
Legumes	3358	3358	3358	5.7
Feed	12258	12233	12392	21.0
Total	61064	57854	58983	100.0
Outputs:				
Grain	14470	17228	14069	23.9
Milk	5106	5365	5369	9.1
Calves, lambs, wool	1004	988	1118	1.9
Leaching	10407	10222	4511	7.6
Volatilization	12833	13904	13647	23.1
Denitrification	5649	5094	3192	5.4
Total	49469	52801	41906	71.0
Unaccounted for	11595	5053	17077	29.0

* Deposition of N from the atmosphere in precipitation and as nitrogen dioxide, nitric acid and particulates.

Table 2. Nitrogen leaching losses from Coates Farm, 1996-97.

Field name	Previous crop (1995-96)	Current crop (1996-97)	N leached (kg ha^{-1})
Field 1	Winter barley	Stubble turnips/Forage maize	8
Field 2	Forage maize	Winter wheat	27
Jarvis Quarry	Winter wheat	Winter barley	4
Gooseacre	Winter barley	Stubble turnips/Linola	25
Shepherd's Piece	Winter wheat	Winter barley	5
Paddimore	Grass ley	Grass ley	16
Peel's Piece	Lucerne	Lucerne	22
Oathills South	Kale	Kale/Forage maize	31
Oathills North	Spring wheat	Winter wheat	6
Cricket Field	Permanent pasture	Permanent pasture	40

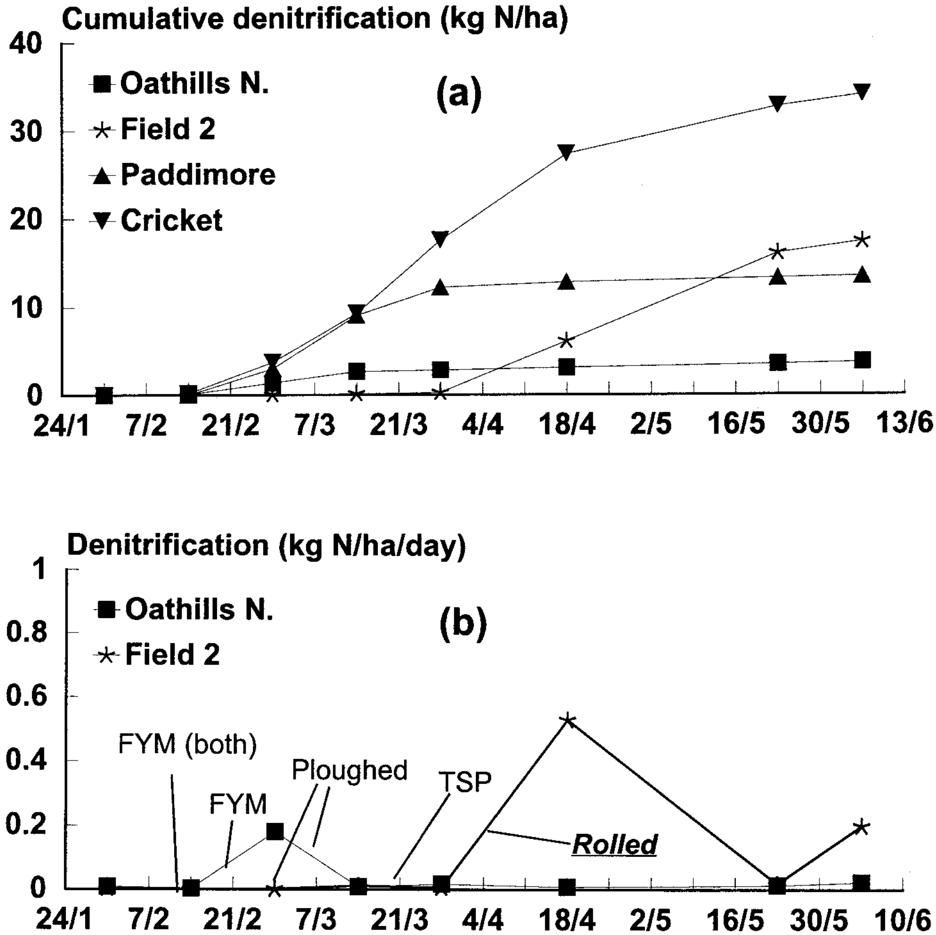

Figure 1. Losses of N by denitrification at Coates Farm (1996): (a) cumulative losses on four fields; (b) daily rates of loss from two arable fields. FYM = farmyard (cattle) manure; TSP = triple superphosphate.

methodology: some parts of the budget cannot be adequately measured. Analyses of the Soil Organic Matter (SOM) and the C:N ratio, made over the duration of the study, may indicate the extent of changes in SOM and help to fill the gaps in the budget. Also, NH_3 losses from housed livestock and stored manures are poorly quantified and we shall attempt to better assess losses from these parts of the system.

Leaching accounted for 8% of the N loss and denitrification 5% of the N loss. Examples of measurements of leaching and denitrification are given in Table 2 and Figure 1, respectively. Both losses show the effects of management, particularly arable versus grassland. Denitrification losses occurred mainly from the permanent pasture, and there were consistent significant differences between grassland and arable: in February 1996, a 2-year grass ley had a denitrification rate of 0.24 kg ha^{-1} d^{-1} and winter barley a rate of 0.03 kg ha^{-1} d^{-1}. Such slow rates are to be expected on the shallow free-draining soil. The compaction through grazing of the permanent pasture and the excreted returns probably explain the greater losses found there. The effects of certain management practices on losses are shown in Figure 1b. The two arable fields, Oathills North and Field 2, are of the same soil type and grew the same crop (Table 2). Losses of N by denitrification were much larger from Oathills North through February and March following a second application of farmyard manure (FYM) to this field only on 21 February. However, the rolling of Field 2, to consolidate the seedbed and encourage tillering, in early April resulted in a large denitrification loss. Consequently, Field 2 lost a total of 20 kg ha^{-1} through the spring and summer of 1996 compared to 4 kg ha^{-1} from Oathills North (Figure 1a).

Mineralization rates (not shown) were also very variable across the farm. Two fields, Gooseacre (winter barley; stubble turnips) and Field 2 (forage maize; winter wheat), in particular showed very rapid rates of net mineralization. There were also sharp increases in net mineralization that coincided with fertilizer N applications and rainfall events. No increases were observed after cultivation, however.

Leaching losses (Table 2) were greatest under the grazed permanent pasture of Cricket Field, but were generally small in this dry year: 288 mm precipitation fell during the September-April period compared to the long-term average 400-450 mm. The smallest leaching losses were measured in fields where active autumn growth was evident. In years with nearer average precipitation, i.e. 1994-95 and 1995-96, losses were larger (Table 1). For these years, a combination of measurements and desk-top estimates gave N losses due to denitrification and leaching of *ca* 5000 and 10000 kg, respectively, for the whole farm, some 60% and 100% more, respectively, than in 1996-97.

In a mixed farming system, N flows from animal waste products are difficult to quantify. The Committee on Long-range Soil Conservation (1993) suggested that the average N use efficiency is about 50% for arable systems; a dairy system is considered to be efficient if 25% of the N entering the system goes to saleable product. The efficiency of Coates Farm at 35% lies midway between the two but with room for improvement. Improvements are most likely to be made by increasing the efficiency of use of manures and slurries. At present 28% of the N in excreta is recovered and spread onto fields; further losses will occur after spreading. If these losses could be decreased then efficiency would increase considerably. However, this may require investment in new and extra storage and handling facilities.

Studies of this nature provide opportunity to identify possible improvements in farming practice. For example, the particular example of rapid denitrification after rolling Field 2 might suggest that eliminating this practice would decrease losses. However, rolling is an essential part of arable production. What is required is more precision for timing activities in relation to the weather, soil conditions and crop status. Finally, although the time step used in the budget is currently a year, N losses from a mixed system are better expressed for the complete rotation. The concluding stages of our study will produce a budget for the full rotation.

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Eight years of ecological and conventional farming at Öjebyn

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Introduction

To investigate the production potentials in ecological farming, specific methodological aspects have to be considered. Firstly, to understand the integrated patterns of nutrient flows and to utilize plant nutrients in a sustainable way, studies need to be carried out on a realistic, whole farm scale. Such case-studies on whole farm situations represent a new type of agricultural research (Kerner & Kristensen, 1993). Secondly, to quantify the various aspects of ecological farming, comparisons have to be made with corresponding conventional systems. Such comparisons can be made either statistically by sampling a number of farms from each of the production systems (Kristensen *et al.*, 1993) or experimentally by comparing the results of the two systems managed at the same farm with repetition in time or space to verify scientific criteria. Repetition in space is often difficult to achieve at this scale, which only leaves the alternative of repetition in time, requiring long-term experiments (Jonsson, 1991; Fagerberg *et al.*, 1992).

The aim of this paper is to report eight years of research to develop ecological food production systems (especially dairy production) in the north of Sweden. A full-scale study comparing ecological farming with conventional farming is being performed at the same time.

Material and methods

The research station

The experimental station is situated 5 km north of Piteå on the coastal plains of northern Sweden, 65°N 22°E. Annual mean temperature is +2.1 °C and total average precipitation 500 mm (Hårsmar, 1991). The station, with a total area of 170 ha suitable for production of forage, barley, potatoes and vegetables, has been in operation since 1944. Soil samples were taken in autumn in each field in each farming system when barley and ley in the establishment year were grown, to determine contents of minerals and organic matter as well as pH (Ståhlberg *et al.*, 1976). The soils are well-drained, limed and in good condition with a pH of about 5.8. Soil texture (0-20 cm depth) contains approximately 16% fine sand, 59% silt, 16% clay and 7% organic matter. The amount of P (P-AL) and K (K-AL) was, on average 103 and 89 mg kg^{-1} air dry soil, respectively (Egnér *et al.*, 1960; SIS, 1993).

Two separate cow-sheds, similarly equipped for 50 dairy cows, are available. On the manure pad, with storage capacity for 12 months, the manure from each shed was kept separately. Each shed also has its own urine pit. The herds receive their feed from specific fields. Manure and urine produced are returned to these respective fields. Forage can be

Table 1. Crop rotation (6 years) and plant nutrient application in the conventional and ecological system.

Crop rotation	Fertilizer
Conventional	
Ley establishment without nurse crop	26 t urine ha^{-1} before sowing
Ley 1st	70 + 50 kg N ha^{-1}
Ley 2nd year	70 kg N ha^{-1} + 26 t urine ha^{-1},
	12 kg P and 24 kg K ha^{-1}
Ley 3rd year	70 + 50 kg N ha^{-1},
	14 kg P and 28 kg K ha^{-1}
Barley	30 t manure ha^{-1}
Pea/oat mixture, potatoes and vegetables	30 t manure ha^{-1}, 17 kg P and 39 kg K ha^{-1}
Ecological	
80% peas and 20% oats with undersown ley	14 t urine ha^{-1} before sowing
Ley 1st year	
Ley 2nd year	14 t urine ha^{-1} after first cut
Ley 3rd year	14 t urine ha^{-1} in early spring
Barley	23 t manure ha^{-1}
Pea/oat mixture, potatoes and vegetables	23 t manure ha^{-1}

Table 2. Seed mixtures for leys, kg ha^{-1}.

Species	Ecological system	Conventional system
White clover (*Trifolium repens*)	1	-
Red clover (*Trifolium pratensis*)	8	5
Timothy (*Phleum pratensis*)	10	12
Meadow-fescue (*Festuca pratensis*)	5	8

stored in tower silos or hay dryers, while facilities are also available for storing silage in round bales. A drier for grain and a storehouse for potatoes are available.

Project description

Two farming systems, based on ecological and conventional principles, are compared in a full-scale study. Apart from milk and beef, also potatoes and vegetables are produced for the local market. The feeding plans are based on the feed produced in the two systems. The 6-year crop rotations in the two systems and their plant nutrient applications are shown in Table 1. The different seed mixtures used to establish the leys in the two systems are presented in Table 2. The project started in 1988 when ecological farming was introduced on half of the total area of the research station. Measurements of crop yields started in 1990, and those of milk yields in autumn of the same year.

Table 3. Main results as an average over eight years of ecological and conventional farming.

	Ecological system	Conventional system
Yield ha^{-1} yr^{-1}		
Leys, kg DM	6167	6840
Barley, kg (87% DM)	4156	3894
Total, kg DM	5241	5433
Energy, ME MJ	56386	59619
ECM per cow, kg yr^{-1}	8050	7950
Milk composition		
Fat, %	4.70	4.60
Protein, %	3.47	3.61
Lactose, %	4.64	4.68

Observations

Crop yields Dry matter yields and mineral contents of all crops were determined for each field by weighing and sampling each load of harvested material. Crops were analysed according to conventional methods.

Feeds and feeding The dairy herds in each system were fed the following rations:

Conventional system: Limited access to forage (1.5 kg DM 100 kg^{-1} liveweight), complemented with a high ration of concentrates.

Ecological systems: Free access to forage (2.25 kg DM 100 kg^{-1} liveweight), complemented with a low ration of concentrates.

Concentrate in the conventional system consisted of barley and a mixture of rape meal (45%), rape seed (9%) and soya meal (46%). In the ecological system, the concentrate consisted of barley, produced on the farm and a mixture of rape cake (37%), rape seed (7%) and peas (56%). The feed was sampled daily and compiled into fortnightly samples, which were analysed.

Milk yield Milk yield of each cow was determined every fortnight and samples for fat, protein and lactose were taken and analysed. The daily yield of energy corrected milk (ECM) was calculated according to Baevre *et al.* (1988).

Results and discussion

The results are presented in Table 3 and illustrate events that occur during the conversion period on a milk-producing farm, where cows have been kept fore more than 100 years and where great emphasis has been given to ley cropping and the production of high quality forage. During the ensuing crop rotation, various results can be considered as differences between the two systems of crop- and dairy production.

The yields from the reseeded pasture and the leys together show for the first eight years (1990-97) that the ecological system produces about 6200 kg DM ha^{-1}, i.e. 10% lower yield than from the conventional system. Barley in the ecological system gave a 7% higher yield than in the conventional system.

Cows in the ecological system produced 1% more milk than in the conventional system. The two herds have an average yield of 8000 kg ECM yr^{-1}. The concentration of milk fat was 0.10%-units higher and the milk protein content 0.14%-units lower in the ecological than in the conventional system.

With relatively high yields from the ecological system and no application of commercial fertilizers and pesticides, the cultivation costs are lower in the ecological than in the conventional system. For the first eight years we recorded 12% lower cultivation costs of forage in the ecological than in the conventional system. The cultivation cost of barley was 3% lower in the ecological system, mainly due to its higher yield.

The N balances are consistently positive in the conventional and negative in the ecological system. The N surplus in the conventional system increased more than the shortage in the ecological system. The phosphorus balances are positive in both systems with a considerably higher surplus (about 10 kg ha^{-1}) in the conventional than in the ecological system. The P balances are not subject to uncertainties by assumptions, and may, therefore, be regarded with more confidence than the N balance calculations. The increased positive K balance over the years in the conventional system reflects the increased input of K through fertilizer and purchased feed, which was not accompanied by an increased output of K. In the ecological system the input and output of K was more balanced.

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The Minderhoudhoeve project: Development of an integrated and an ecological mixed farming system

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Introduction

The Ir. A.P. Minderhoudhoeve is the experimental farm of Wageningen Agricultural University at Swifterbant in Oostelijk Flevoland, The Netherlands. The farm covers an area of 247 ha on a well-drained young sedimentary calcareous silty loam soil reclaimed from the sea some 40 years ago. On the farm a start was made in 1995 to set up two prototypes of mixed farming systems: an integrated and an ecological one. Both farms have their own sets of objectives and constraints, to which management is adapted. A common feature is the integration of animal husbandry and crop production within the farm. An intensive exchange of products and services between these enterprises takes place. Besides, much attention is paid to the quality of the production process and products. The aim of this research project is not to compare both mixed farming systems, but the project focuses on the development of sustainable farming systems through monitoring, analysis and adaptation.

The motivation for this type of farming systems research can be explained by the problems that conventional, specialized farms are increasingly confronted with. During the 1980s it became evident that Dutch and other West-European agricultural production systems were not sustainable. They could be characterized by narrow crop rotations, high external inputs of chemical fertilizers, pesticides and concentrates with low efficiencies per unit of product, and latent unemployment. To decrease these undesirable effects of increased intensification and to utilize symbiosis between several objectives, a 'renaissance' of mixed farming systems – on farm or regional level – is desirable.

Advantages of mixed farming systems are:

- Reduction of external inputs and increase of their efficiency through the use of home-grown, energy-rich feedstuffs with a low nitrogen content (like maize silage, grain silage and fodder beets) and by-products like straw, potato waste and beet pulp.
- More efficient nutrient use of animal manure through timing of application and manipulation of composition which results in a reduction of nutrient losses through volatilization, denitrification and leaching.
- Incorporation of short-term grasslands (up to 4 years) into the crop rotation which reduces the accumulation of soil nitrogen typical for long-term grasslands and results in a

more efficient utilization of mineralized nitrogen after ploughing-out.
- Broadening the crop rotation which results in a decreased use of herbicides and pesticides and gives higher yields as a result of less problems with soil-borne pests and diseases.
- Optimal use of legumes for biological nitrogen fixation.
- A more even spread of labour input and spreading of income risks.

Farm profiles

For the farming systems research, a total area of 225 ha is used: 135 ha for the integrated farm and 90 ha for the ecological farm. Both farms have a combination of dairy farming, arable farming (including field-grown vegetables) and sheep farming.

On the ecological farm there is – in principle – no use of artificial nitrogen fertilizer and biocides and about 4% of the farm area is used for nature to establish an ecological infrastructure. The most important objective of the integrated farm is an efficient and high production by minimizing the nitrogen surplus and biocide use per unit of product, while maintaining product quality. The ecological farm will be developed in such a way that the farm is a model for a high-productive, ecological farm on a good soil with low emissions per unit of area. The integrated objective (more efficient use of inputs) and the ecological one (closing cycles) can inspire each other. A good example of this is the intensive use of legumes on the integrated farm, which are indispensable in ecological farming systems. Both mixed systems are based on lower external inputs and a (more) natural crop protection compared to specialized farms.

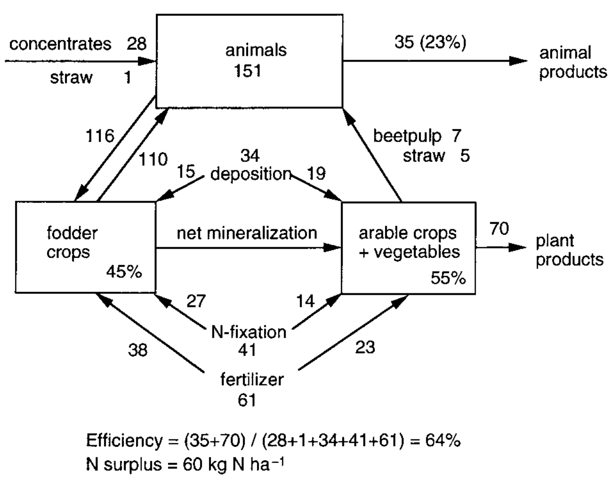

Figure 1. Nitrogen fluxes (kg N ha^{-1} yr^{-1}) on the integrated mixed farm, according to the designed prototype (see Table 1). The percentages refer to N-use efficiency at the livestock level (23%), the farm area used for fodder crops (45%), and arable crops including vegetables (55%).

Table 1. The calculated annual nitrogen balances of the two mixed farms on the Minderhoudhoeve, compared with the 'open' Dutch agriculture (1985-86). The mid-eighties were the peak years of N surpluses in Dutch agriculture. Between brackets the results are given for 1996, the second year of transition.

	Ecological	Integrated	Netherlands (1985-86)
Input (kg N ha^{-1} yr^{-1})			
- Fertilizer	0 (0)	61 (82)	248
- Animal manure	0 (0)	0 (0)	98
- Deposition	34 (34)	34 (34)	45
- Biological N_2-fixation	48 (94)	41 (24)	4
- Compost	32 (15)	0 (0)	0
- Roughages	0 (0)	0 (19)	
- Concentrates	20 (29)	29 (34)	65
Total	134 (172)	165 (193)	460
Output (kg N ha^{-1} yr^{-1})			
- Crops	39 (38)	70 (68)	48
- Milk	27 (28)	30 (28)	35
- Cattle	4 (10)	5 (6)	8
Total	70 (76)	105 (102)	91
Input–Output (kg N ha^{-1} yr^{-1})	64 (96)	60 (91)	369
Output/Input (%)	52 (44)	64 (53)	20
N surplus (kg N per kg N product)	1.3 (1.3)	0.6 (0.9)	4.1

Results and discussion

Calculations show that – with maintenance of acceptable to good production levels – on both mixed farms considerable reductions in nitrogen losses are possible, per hectare as well as per unit of product (see Table 1). On both farms, the N surplus is less than 100 kg N ha^{-1} yr^{-1}, thus well below 25% of the level in Dutch 'open' agriculture some 10 years ago. Nowadays, the average milk quotum in The Netherlands is about 5500 kg per hectare of cultivated land. This is equivalent to the milk production on the integrated farm and some 15% above the level on the ecological farm. The main constraint for a high milk production per unit of area on the ecological farm is the restricted use of purchased concentrates in ecological agriculture. On the integrated farm only 45% of the total area is used for growing fodder crops (grass-clover, maize silage and grain silage), while on the ecological farm this is 65%, which is representative for the Dutch average. Hence, the area of arable crops and field vegetables on the integrated farm is 50% larger in comparison with the 'open' Dutch agriculture. This explains the high nitrogen output by crops on the integrated farm and demonstrates very clearly the good production potential of this site and the advantages of mixed farming systems. As an illustration, the N flows on the integrated mixed farm are presented in Figure 1.

During the first transition year (1995), the whole area of the ecological farm was used to grow fodder crops without using fertilizers and biocides, whereas on the greater part of the integrated farm arable crops were grown. Therefore, roughages (maize and grass-clover silage) had to be imported on the integrated farm for the winter period 1995-96. This explains the input of N via roughages on the integrated farm in 1996 (Table 1). From 1996 onwards, the integrated farm is self-supporting with regard to roughage production. On the ecological farm, the input of N via biological fixation was very high due to the large area of grass-clover and higher than expected yields. Therefore, the use of compost was restricted in autumn 1996. Between 1996 and 1998 the grass-clover area has been reduced gradually. On the integrated farm, the level of fertilizer N use has been reduced since 1996 due to a further replacement of grass monocultures by grass-clover mixtures, leading to an increased input via N_2-fixation. Besides, on this farm part of the purchased protein-rich concentrates has been replaced by beet pulp, whereas all cereal straw is now fed to the animals (Lantinga & Van Bruchem, 1998).

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NUTRIENT MANAGEMENT IN MIXED FARMING SYSTEMS

Nitrogen cycling and nitrogen surpluses in mixed farming systems: What are the determinants?

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Introduction

Agriculture involves the production and harvesting of crops, the conversion of crops into animal products and the recycling of wastes and by-products through soils and animals. Basically, agriculture may be considered as a process in which nutrients are transferred in a cyclic way from the soil compartment (1), via the crop (2), via animals and men (3), via manure (4) to the soil again (Figure 1). A mixed farm can be defined as a system in which these four processes are all playing a role. For nitrogen (N), there are inevitable losses in each step of the cycle. Losses and exports are compensated by the input of urban and industrial wastes, biological fixation, deposition, net mineralization of soil organic matter, manufactured fertilizers and animal manure (or, indirectly, feedstuffs).

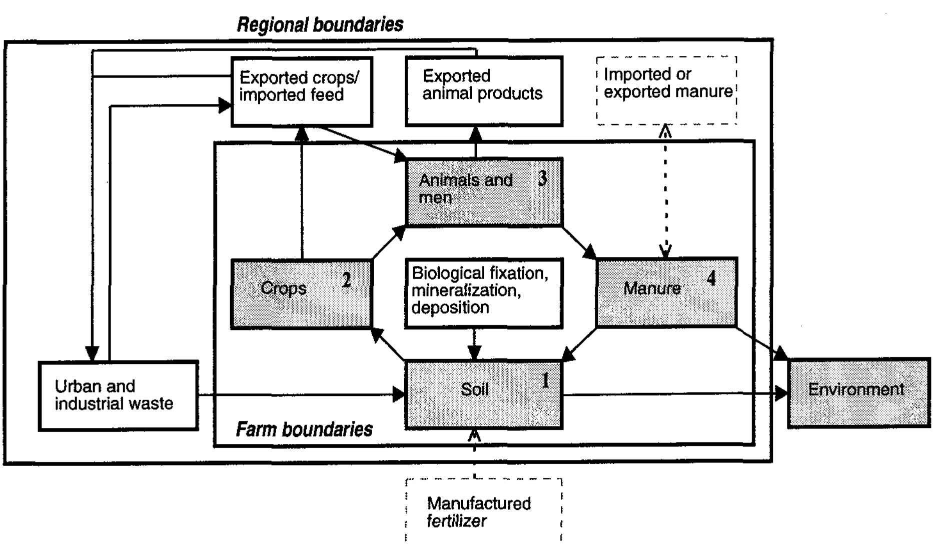

Figure 1. Nitrogen fluxes in a mixed farming system.

N surplus can be defined as the difference between total N input into the farm system from external sources and the total amount of N in products exported. This surplus is considered indicative of losses to the environment. Isermann (1993) showed that in the 1980s, N surpluses in Western Europe ranged from 103 kg ha^{-1} yr^{-1} in Sweden to 367 kg ha^{-1} yr^{-1} in The Netherlands. The magnitude of the surpluses is determined by management factors and pedoclimatic conditions. Another decisive factor is farm type. In many parts of Europe, not at least in The Netherlands, mixed farms have become a rare phenomenon. Many farms have specialized into either livestock farming (combined or not with grass production) or arable farming. Consequently, re-cycling of wastes and by-products is no longer a self-evident activity. Many livestock farmers and arable farmers have selected only those animal types, crop types and input sources that best suit them economically. Livestock farmers substituted crop products, including crop residues by imported, highly digestible concentrates (Figure 2), whereas arable farmers extended or even fully substituted the use of manure and legumes by manufactured fertilizers (Figure 3). Moreover, specialized farms have, by definition, externalized part of their activities (including the associated losses) to others farms, to other compartments of society including the environment, or even to other continents. In the following sections we address the large scatter in N surpluses among farms. In connection, we explain some of the reasons behind this scatter.

Effect of the farm type on nitrogen surpluses and output-input ratios

Nitrogen surplus on specialized arable farms in The Netherlands ranges from 50 to 200 kg ha^{-1} yr^{-1}. Output-input ratios (O/I) on these farms ranges from 0.40 to 0.70 kg kg^{-1}, the N surplus per kg N output from 0.5 to 1.5 kg kg^{-1} (Stouthart & Leferink, 1992; Wijnands *et al.*, 1992; Van Faasen & Lebbink, 1994; Schröder *et al.*, 1996; Tjalkes, 1996; Wijnands & Van Leeuwen-Haagsma, 1997). Corresponding values for Dutch dairy farms (an approx-

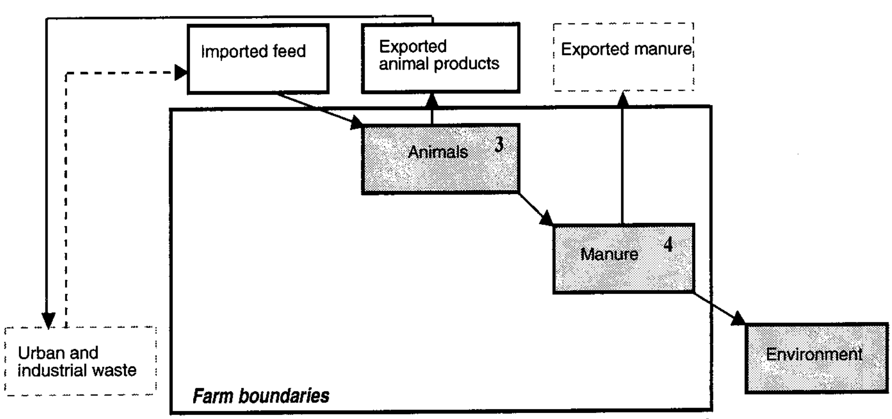

Figure 2. Nitrogen fluxes on a specialized livestock farm.

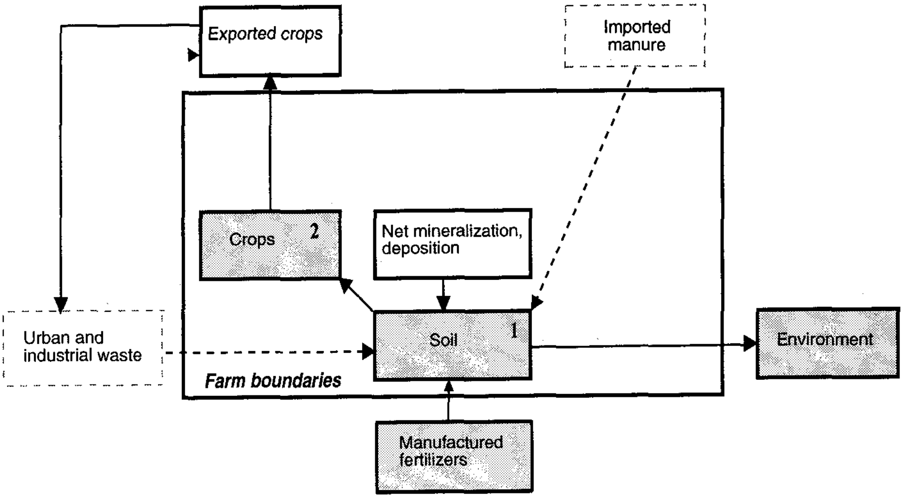

Figure 3. Nitrogen fluxes on a specialized arable farm.

mation of the mixed farm concept) range from 100-500 kg ha^{-1} yr^{-1}, 0.15-0.35 kg kg^{-1} and 2-5 kg kg^{-1}, respectively (Souwerbren, 1991; Aarts *et al.*, 1992; Korevaar, 1992; Baars *et al.*, 1993; Tjalkes, 1996; Van Keulen *et al.*, 1996; Zaalmink, 1997). None of these characteristics appears to have a clear relationship with the farming policy (i.e. conventional < > integrated < > organic). Balance sheet calculations at the farm level for a limited number of dairy farms in Poland and Lithuania point at lower N surpluses (50-200 kg ha^{-1} yr^{-1}) than in The Netherlands. O/I's on these farms range from 0.10 to 0.65 kg kg^{-1} and N surpluses per kg N output range from 0.5-7.0 kg kg^{-1} (Sapek, 1996; Sapek, 1997; Anonymous, 1998), confirming the conclusion of Isermann (1993) that the differences in O/I's among countries are smaller than the differences in surpluses per unit area.

It should be noted that many dairy farms either import concentrates (Western Europe) or export part of their crop products (Eastern Europe). Following Figure 1, the whole-farm O/I ($O/I_{wholefarm}$) can be described as:

$$O/I_{wholefarm} = (O/I_{crop\text{->}milk} + (1 - FFNIM) \times FCNEX / (1 - FCNEX)) / (((1 - FFNIM) + (1 - FFNIM) \times FCNEX / (1 - FCNEX)) / O/I_{soil\text{->}crop} - (1 - FNLOSS_{man\text{->}soil}) \times (1 - O/I_{crop\text{->}milk}) + FFNIM)$$

where

$O/I_{crop\text{->}milk}$ is the O/I for the conversion of feedstuff N into milk N;

$O/I_{soil\text{->}crop}$ the O/I for the conversion of N inputs to the soil (manures, fertilizers, deposition, legumes) into harvestable crop N;

FCNEX the fraction of the produced crop N that is exported;

$FNLOSS_{man\text{->}soil}$ the fraction of the manure N that is lost during storage and application; and

FFNIM the fraction of the feedstuff N imported (with feedstuff N = non-exported crop N and imported feedstuff N).

For FCNEX values approaching 1.00 (specialized arable farms), the formula yields

$O/I_{wholefarm} = O/I_{soil\text{->}crop}$

Assuming values for $FNLOSS_{man\text{->}soil}$, $O/I_{soil\text{->}crop}$ and $O/I_{crop\text{->}milk}$ of 0.10, 0.60 and 0.25, respectively, an $O/I_{wholefarm}$ of 0.25 can be calculated for a self-supporting dairy farm. A dairy farm importing 20% of the feedstuffs (on N basis) would achieve an $O/I_{wholefarm}$ of 0.29, whereas a dairy farm exporting 20% of the crops (on N basis) would achieve an $O/I_{wholefarm}$ of 0.36. The N surplus per kg N output for these three different farms would be 3.0, 2.4 and 1.8 kg kg^{-1}. These calculations show that minor differences in farm type can have a large impact on the O/I ratio and the surplus per unit product. Therefore, these characteristics do not give exclusive information on the ability of a farmer to grow his crops and feed his animals efficiently. Desintegration of a mixed farm may, therefore, be associated with an apparent improvement efficiency.

Manipulation of the nitrogen surplus

The quality of individual feedstuffs and the composition of the ration as a whole, together with the ability of the animal to digest rations of a given quality (animal type), undoubtedly affect the N surplus and the O/I. Within the scope of this paper, however, we restrict ourselves to techniques to reduce the N surplus at the soil-crop level.

Crop choice and nitrogen source

Crops strongly differ in their ability to recover N from the soil and in their allocation of N to harvested plant parts. N surpluses associated with the production of a crop may thus vary from −10 (winter wheat) to +90 (ware potatoes) kg N ha^{-1} yr^{-1} (Smit & Van der Werf, 1992). Consequently, crop choice and cropping frequency have a strong impact on N surplus.

Manure and, in organic farming, legumes are the most important sources of N on a mixed farm. The production of manufactured fertilizers once allowed farmers to specialize into arable farming and remove legumes from the rotation. The use of manufactured fertilizers is associated with smaller losses (but not always) than the use of manures. Manure comprises ammonium and part of that is inevitably volatilized, even when incorporated into the soil. Besides, on heavier soil types manures are preferably applied in autumn to minimize damage to the soil structure. This practice exposes N to run-off, leaching and denitrification losses. Sequestering N in cover crops may improve the situation slightly (Schröder *et al.*, 1997a). When applied in spring, N from manure is neither fully available to the crop as mineralization is never perfectly synchronized with the uptake pattern of the crop. This is true for any other organic N source (e.g. green manures, including legumes, crop residues, ploughed leys). Moreover, decomposition of organic N usually takes more than just one season. Residual effects from manure and other organic N inputs may accumulate over the years, however, and this may gradually improve the apparent recovery. The impact of crop choice and N source on whole-farm N surpluses is illustrated in Table 1.

Input level

A reduction in N application to rates below the economic optimum can contribute to the reduction in the surplus, both per unit area and per unit product, especially when the recovery is negatively related to the input rate, as illustrated for silage maize in Table 2. The long-term consequences of sub-optimal application rates deserve attention, as crops may benefit for many years from soil fertility built up in the past (Whitmore & Schröder, 1996). Therefore, surpluses of farms that have recently adopted a low-input policy need to be interpreted with great caution.

Fine tuning

One other way of reducing the surplus is to substitute routine applications of N by site-specific applications combined with increased spatial and temporal precision. Recommendations taking account of the field history and the variable natural availability of N may contribute to this. It seems too simple to just adjust rates to the expected N uptake if

Table 1. Calculated N surplus (kg ha^{-1} yr^{-1}) associated with economically optimal N rates (including the input of 40 kg N ha^{-1} yr^{-1} via atmospheric deposition), as affected by the cropping frequency and the nutrient source options on potatoes and sugar beets (Schröder *et al.*, 1993).

Cropping frequency (%) of:			Nutrient source on	
Wheat	Beets	Potatoes	potatoes and beets*	N surplus
75	25	0	SAF	52
			SM	67
			AM	88
75	0	25	SAF	55
			SM	77
			AM	108
50	25	25	SAF	81
			SM	108
			AM	159
25	50	25	SAF	87
			SM	139
			AM	211
25	25	50	SAF	90
			SM	148
			AM	231

* SAF, spring applied manufactured fertilizer;
SM, combination of spring applied manure (66% of required total N input) and spring applied manufactured fertilizer (33% of required total-N input);
AM, combination of autumn applied manure (66% of required total N input) and spring applied manufactured fertilizer (33% of required total-N input).

Table 2. N surplus per unit area (kg ha^{-1} yr^{-1}) and per unit product (kg t^{-1} DM) associated with economically optimal and sub-optimal N rates (including the input of 40 kg N ha^{-1} yr^{-1} via atmospheric deposition), in organic-grown silage maize (after Schröder *et al.*, 1998).

	Mineral N supply (kg N ha^{-1})*:					
	195	175	155	135	115	95
Relative DM yield	100	99	97	94	89	84
Surplus per unit area	172	138	106	75	45	18
Surplus per unit product	11.6	9.6	7.6	5.5	3.5	1.5

* Supply of inorganic N comprising the soil mineral-N in early spring (0-60 cm) and ammonium-N from spring-applied slurry.

no account is taken of the pedoclimatically determined N recovery. Unfortunately, yield level expectations can be negatively related to recoveries, so these factors may work in opposite directions with respect to economically optimal rates.

When N sources with a low C to N ratio are used (including manufactured N fertilizers), it is cautious to postpone application until just before planting or to apply N in split dressings, as on grassland. A partial delay in application can further improve the O/I as it enables the farmer to fine tune the rate to the instantaneous mineralization rate and crop demand. Postponement can have serious drawbacks, however, through negative effects of early N deficiency, traffic-induced crop and soil damage or due to the inefficiency of the late dressings under dry weather conditions (Schröder, 1997).

In addition to timing, placement also can improve O/I. Placement can especially be relevant in row crops with limited lateral root extension and under dry conditions. Even with manure it is technically possible to position the N close to the plant rows (Schröder *et al.*, 1997b).

Conclusions

- N surpluses and output-input ratios should be interpreted cautiously.
- Management skills of individual farmers can only be evaluated correctly with efficiency indices at the level of the whole farm, when comparisons pertain to groups of farms that are homogeneous in terms of pedoclimatic conditions, crops and animal types and the extent to which farm activities are externalized.
- For the soil-crop compartment, the N surplus and the output-input ratio is affected by management factors, comprising N application rates and methods, especially timing and placement.

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Using nutrient budgets as management tools in mixed farming systems

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Introduction

Management of nutrients within mixed farming systems is complex as a result of the coincident spatial and temporal components of nutrient flows (Watson & Stockdale, 1997). The use of crop rotations and the inclusion of grazing animals requires that nutrient management is planned and understood over periods of longer than a single crop or growing season. Nutrient budgets are rapidly becoming an important and internationally recognized indicator of sustainable land management. Where budgets can be simply and rapidly compiled for farms, they can be used to assess the nutrient use efficiency of any system, and to provide a basis for nutrient management decisions.

A large number of budgeting studies have been carried out in a range of farming systems (e.g. Frissel, 1978; Barry *et al.*, 1993), but it is often difficult to compare results as they are based on the use of different conceptual models. The conceptual models on which nutrient budgets are based vary from very simple budgets calculated at the farmgate level (e.g. Fowler *et al.*, 1993; Breembroek *et al.*, 1996) to more complex budgets which include cycling of N within system components (e.g. within the soil). This paper illustrates the impact of budget formulation on predictions of nutrient use within mixed farming systems. It also demonstrates the ability of complex budgeting models to quantitatively describe nutrient flows within mixed farms.

Material and methods

Watson & Atkinson (1998) defined three conceptual models known as Economic Input:Output (EIO), Biological Input:Output (BIO) and Transfer:Recycle:Input:Output (TRIO), characterized by increasing complexity. These models are described briefly below, for full details see Watson & Atkinson (1998).

Economic Input:Output (EIO) budget

The EIO budget is based entirely on farm management information on the quantities of N purchased and sold over the farmgate. This is a simple approach that allows budgets to be calculated from farm records. It assumes the existence of steady state conditions over the whole farm: N input = N output.

Biological Input:Output (BIO) budget

In addition to information on purchases and sales of N over the farmgate, inputs from symbiotic and non-symbiotic N_2-fixation and atmospheric deposition are included. As in the EIO budget, this type of budget also assumes the existence of steady state conditions on the farm, N input = N output and any calculated surplus of inputs over known outputs is assumed to be lost from the system. Inputs and outputs were based on a combination of literature predictions and farm records of purchases and sales, crop, manure and animal management. Gaseous losses were calculated as the total of ammonia volatilization and denitrification during animal housing and manure storage and following field application of manure. Thus the calculated surplus in the BIO budget is assumed to equal the total accumulation of N in soil plus leaching loss.

Transfer:Recycle:Input:Output (TRIO) budget

The TRIO budget includes selected major internal soil N fluxes (mineralization and immobilization), largely predicted from the literature in addition to information included in the BIO Budget. Thus it allows for a build-up or decline in soil N and can be used where steady state conditions are unlikely to exist, for example, following a land use change. In the TRIO budget the calculated surplus is thus assumed to be lost by leaching. This gives the TRIO budget increased flexibility over both EIO and BIO budgets. A further potential benefit of the more complex TRIO approach is the ability to predict the internal cycling of N within a farming system. This allows an analysis of the reliance of the system on internal nutrient sources, an important concept in relation to sustainability.

Impact of budgeting approaches on the N budget for a mixed farm

The EIO, BIO and TRIO budgets have been applied to data collected over a 2-year period from the SAC Woodside Organic Unit in NE Scotland. Woodside has held the Soil Association symbol for organic production since 1992 (The Soil Association 1992). The 56.7 ha farm includes 13.6 ha permanent pasture and 43.1 ha arable land which is farmed in a 6-year rotation. The 6-year rotation comprises a 3-year ley of grass and white clover

Table 1. EIO, BIO and TRIO Budgets for Woodside Organic Unit.

	EIO	BIO	TRIO
Purchased inputs	52	52	52
Biological inputs	-	99	99
Total inputs	52	151	151
Sold in produce	46	46	46
Gaseous loss	*	24	24
Runoff	*	2	2
Soil storage	*	*	9
N surplus	+8	+79	+70

*Not calculated

followed by a spring cereal, potatoes and a spring cereal undersown with grass and white clover. Approximately 50 suckled calves per annum are finished on the Woodside Unit and 200 ewe hoggs graze the grassland.

The budgets in Table 1 illustrate clearly that the EIO Budget is inappropriate for farming systems based on biological nitrogen fixation, as it does not account for this process. The BIO budget is adequate for predicting the conversion of imported nutrients into saleable produce. The major difference between the BIO and TRIO budgeting approaches is the inclusion of a component that describes the contribution of N to soil organic matter in the latter. The decrease in N unaccounted for between the BIO and TRIO budgets suggests that the TRIO budget was at least partly successful in predicting changes in soil organic matter, since it is widely accepted that organic N increases under grassland (Clement & Williams, 1967). The net change in soil organic nitrogen across the farm as a whole would be too small to detect analytically. The small calculated change was due to the assumption that there was no net change in soil N across one rotation, the increase in soil N, therefore, originated from the permanent pasture, where it was calculated to accumulate at a rate of 34 kg N ha^{-1} yr^{-1}.

Ability of the TRIO budget to describe internal farm nitrogen flows

The formulation of the TRIO Budget is based on a series of smaller budgets relating to individually managed spatial areas of the farm (for example, permanent pasture, housing). Thus flows between these areas of the farm are derived as part of the overall budgeting process. Figure 1 illustrates how this information can be used to diagrammatically represent the flows of nutrients within the whole farm system. The value of the net transfer of N from grass-clover ley to arable was 30 kg N ha^{-1} yr^{-1} (assuming that only part of the rotational grass area was ploughed in any one year). The average transfer per ha from rotational grass to arable was 248 kg N yr^{-1}, this was calculated using the assumption that all the N stored during the ley-phase was released during the arable phase. However, it was assumed that the total N stored during the ley-phase was released in a 4:3:2 ratio (Granstedt, 1992), during the three years of arable cropping. The largest input to the ley-phase was through biological nitrogen fixation, calculated with a model based on the increase in yield of a mixed grass and white clover sward over a pure grass sward (Watson & Goss, 1997). The transfer of N from the arable to the ley-phase was calculated from the total N stored in the soil during the arable phase plus N in the living understorey of grass and clover beneath the final arable crop in the rotation. Full details of these calculations can be found in Watson (1995).

Conclusions

If N budgets are to be used to compare different agricultural systems, both as a means of improving N management at the farm level and assist policy makers, there is a clear need for standard methodology. It is important to recognize that the most appropriate methodology depends on the purpose of formulating the budget. Whole farm nutrient budgets provide one way to assess the sustainability of a farming system, but seem to have

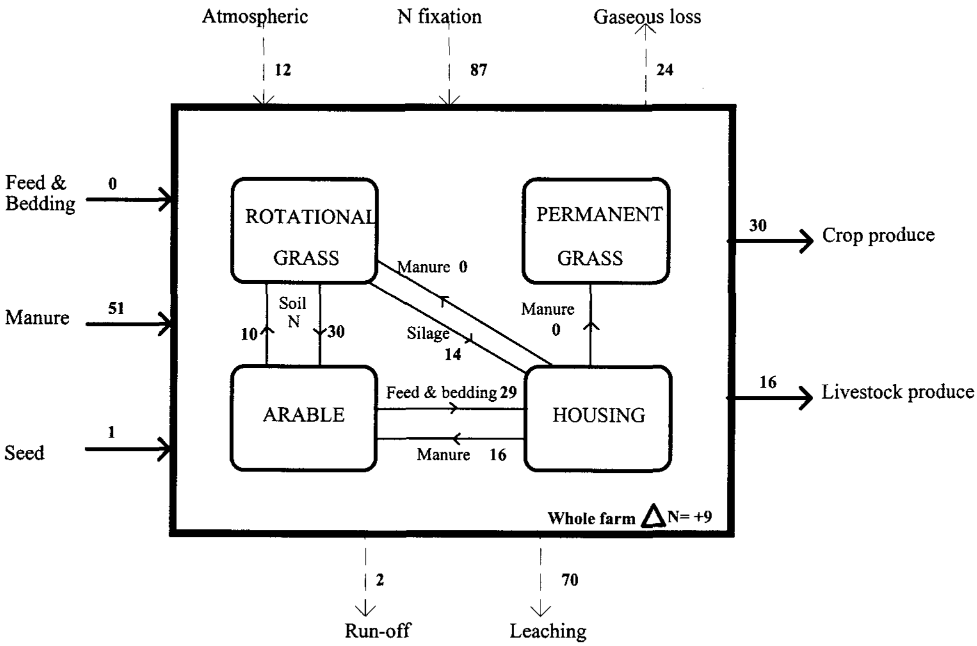

Figure 1. Diagrammatic representation of N flows at Woodside (kg N ha^{-1} yr^{-1}) – based on the TRIO budget.

only academic interest. However, practical management applicability in planning long-term nutrient application and in the use of manures, TRIO approach allows farmers to examine what-if scenarios and better plan nutrient management.

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Problems associated with nutrient accounting and budgets in mixed farming systems

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Introduction

Nutrient accounting has been used for decades by many researchers and advisors to estimate appropriate nutrient management, the potential impact of different agricultural systems on the environment and how sustainable different systems are. Materials and methods used to calculate nutrient balances vary with the objectives, but also and primarily among research teams with similar goals. Our objective was to review from the literature strategies for nutrient accounting and discuss problems associated with different approaches. We will suggest common definitions of concepts and comprehensive layouts that might be used in nutrient accounting.

Literature review

The main literature we reviewed has been summarized in the references. Our interpretation has been recapped in this paper.

The criteria for nutrient accounting

Nutrient accounting can be used in methods whose objective is to form a basis for regulation of nutrient emissions from agriculture. Then the most appropriate criterion is to look at the farm operation as a whole system. In addition to obligations to comply with environmental regulations, the farmer, on the other hand, might also be interested in using nutrient accounting as a management tool to optimize nutrient efficiency within the farm. The farmer's criterion is, therefore, related to budget making that should be based on more precise accounting of the farm's internal nutrient cycles.

Terminology of nutrient balances

Nutrient accounting is usually summarized by calculating the nutrient balance of a particular system that describes all potential losses from a system. Van Bol *et al.* (1997) compared three accounting systems and their balances. They concluded that the methods were not comparable and thus called for standardization, because different important inputs and outputs were omitted due to convenience (or lack of information), rather than negligence. It is clear though, after reviewing the literature, that definitions of the term nutrient balance vary considerably, which leads to confusion, misunderstanding and misuse. The term nutrient balance needs a non-negotiable and common definition.

Nutrient imbalances
Internal nutrient balances within a farming system are often calculated to identify potential sources of losses. When these internal balances are summarized they should add up and equal the farm nutrient balance, which is rarely the case in the literature reviewed. This is not because of miscalculations but because of internal inconsistent definitions of nutrient terms made by the authors.

Negative balances
A nutrient balance that identifies losses from a system that transforms nutrients from one stage to another can in reality never be negative. An accounting system that results in a negative nutrient balance only implies that important inputs or processes are unaccounted for. Negative balances often occur in accounting systems where N_2-fixation and and/or changes in soil reserves as a result of net mineralization or immobilization are not accounted for. Their importance depends on the objectives of the accounting system.

Dilution effects
Nutrient balances used to evaluate the environmental impact of a particular system are often published as mean balances ha^{-1}. Here, some precautions have to be made, because of possible inappropriate dilution effects. Mixed farms have variable access to natural or semi-natural areas for grazing, which often contributes relatively little to the whole farm production and nutrient losses. To include these terms in a mean balance ha^{-1} without any corrections is inappropriate. Also, means based on partial means with negative accounts (numbers) do not give an appropriate estimate of the environmental impact of the system and might result in inappropriate discrimination among farms.

Results and discussion

This review and others show the necessity of common rules and layouts for nutrient accounting and balances. Our suggestions for improvements of the current situation follow below.

The rules of nutrient accounting

- Meaningful processes build-up the accounting system. These processes move and transform nutrients from one stage to another. Depending on the objectives and criteria, a unit can be a single plant, a field, an animal, a herd, a farm, a community, etc.
- Each unit has its boundary, where nutrient inputs (I) and outputs (O) are registered (accounted) over a given period of time. The inputs are all nutrients that enter the unit randomly or systematically. The outputs are all nutrients products leaving the unit in useful products.
- All units have a nutrient capital (a property) at the beginning (c_{in}) and the end (c_{out}) of a

given period of time. The difference between c_{in} and c_{out} describes changes or movements (m) of capital in an unit.

- The net difference between nutrient input and output, i.e.:

  $$I - O + m$$

  is called the nutrient balance, i.e. the quantification of the estimated nutrient change in that unit. Sometimes it may be impossible or irrelevant to differentiate between outputs and capital changes. A good example is a field or a soil account where it can be difficult to distinguish mineralization from nutrient accumulation/depletion. Therefore, the balance describes the potentially irreversible nutrient loss from an unit. Lost nutrients can only re-enter accounts as random inputs.
- A sub-unit is a part of a larger main unit. However, all units obey the same rules and definitions of accounting. The sum of nutrient balances from all sub-units within a larger main unit has to equal the nutrient balance of that main unit.
- The volume or quantity of a nutrient leaving one compartment cannot change during transport to another compartment.

Nutrient accounting to evaluate the environmental impact of agriculture

The most meaningful compartment for assessment of the nutrient environmental impact of a farm operation is the nutrient balance of the whole farm unit. The advantage of using this balance is that most information needed to calculate the nutrient balance of a farm is already at hand. This approach will be introduced as a policy instrument for The Netherlands in 1998 (Munters, 1997). Also, Halberg *et al.* (1998) suggest a similar approach to regulate N-emission from agriculture in Denmark.

Table 1 shows a comprehensive layout and components for a farm account, based on the rules of nutrient accounting described before. Actual data are derived from on-farm studies in Denmark.

Nutrient accounting and budgets in mixed-farm management

Using nutrient accounting as a farm management tool, however, needs new criteria and methods that monitor in more detail the internal nutrient flows on the farm. Weissbach & Ernst (1994) have given an excellent summary of methods to optimize on-farm nutrient efficiency. Here, we concentrate on how nutrient efficiency can be recorded in a sequential system of accounting and budgeting. The most meaningful accounts for this purpose are livestock accounts, field accounts and storage accounts. Comprehensive layouts for the respective nutrient balances for each type of account are shown in Table 2, based on the accounting rules described above. Same sources of data as those of Table 1 are used.

A separate livestock account has to be established for each type of herd within the farm. The most important information for a useful livestock account is to obtain the true quantity and nutrient composition of the systematic inputs and in particular inputs from internal sources. This is because the feed nutrient analysis gives the best checking point for the internal nutrient recycling efficiency.

Table 1. Comprehensive layout for a mixed farm account with a respective nutrient balance (here, kg N ha^{-1} yr^{-1}). Data are from two dairy farms and one pig farm in Denmark (Halberg *et al.*, 1998).

Farm account	Inputs: Dairy 13	Inputs: Dairy 5	Inputs: Pig 19	Outputs	Outputs: Dairy 13	Outputs: Dairy 5	Outputs: Pig 19
Systematic components							
N-fixed	0	92	0	Milk	53	32	0
Fertilizers	113	0	71	Meat	14	5	128
NH_3 to straw	8	0	0	Crops	0	0	99
Feed	148	42	393	Manure	0	0	55
Random components							
Precipitation	21	21	21				
Capital components (m)							
				Livestock	−1	0	0
				Feed	−2	−3	0
				Manure	−8	−24	23
				Soil	0	0	0
Total	290	155	485		56	10	305
Farm balance					234	145	180

A separate field account has to be made for each field within the farm, if the accounting is to be efficient for nutrient management. Each field has its unique physical and topographical properties that have to be considered when nutrient budgets are made. Also, these properties are part of the farm's cultivation design (set-up). The most challenging and central objective for these accounts is to make accurate estimates on plant available nutrients in the manure and to estimate the nutrient carry-over capacity in a crop rotation system or long-term pastures. One can expect that the accuracy will increase with time when the farmer becomes more experienced in using the benefits of systematic accounting.

Keeping track of the nutrient dynamics is particularly important for keeping good records of manure utilization. This is because manure application occurs in pulses that do not always coincide with other internal accounts, and it is important to monitor the nutrient content of the stored manure more frequently than that of other stores. A separate manure account is needed for each storage unit on the farm.

A feed storage account is not always meaningful and can easily be included in the livestock account. It may be useful for estimating the feeding efficiency and to estimate how well the feed is utilized on the farm.

Appropriate and meaningful time scale and stock taking for each account can vary from a few months to years. However, regular synchronization of internal accounts with the farm account is important to double-check all balances. This is fairly easy to do in an organized accounting system as shown in Table 2.

Table 2. Comprehensive layouts for internal farm accounts with respective nutrient balances (here, kg N ha^{-1} yr^{-1}). Data are from two dairy farms and one pig farm in Denmark as in Table 1 (Halberg *et al.*, 1998).

Inputs	Farm type and No.			Outputs	Farm type and No.		
	Dairy 13	Dairy 5	Pig 19		Dairy 13	Dairy 5	Pig19
Livestock account							
Systematic components							
NH_3 to straw	8	0	0	Milk	53	32	0
Purchased feed	148	42	393	Meat	14	5	128
Feed from storage	129	73	0	Sold manure	0	0	55
Grazed forage	37	88	0	Stored manure	205	86	197
				Grazing manure	31	74	0
Capital components (m)							
				Livestock	−1		
Total	322	203	393		302	197	380
Livestock balance					20	6	13
Field account							
Systematic components							
Manure from storage	192	99	139	Stored feed	127	70	0
Manure under grazing	31	74	0	Grazed feed	37	88	0
Fertilizers	113	0	71	Crops	0	0	99
N-fixed	0	92	0				
Random components							
Precipitation	21	21	21				
Capital components (m)							
				Soil store	0	0	0
Total	357	286	231		164	158	99
Field balance					193	128	132
Storage account							
Systematic components							
Manure from livestock	205	86	197	Manure used	192	99	139
Feed from field	127	70	0	Feed used	129	73	0
Capital components (m)							
				Feed	−2	−3	0
				Manure	−8	−24	23
Total	332	156	197		311	145	162
Storage balance					21	11	35
Farm balance from Table 1					234	145	180
Balance check balance	Livestock + Field + Storage balance =				234	145	180

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Soil processes influencing nitrate leaching from recently sown grass leys

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Introduction

Grassland soils are frequently regarded as representing a relatively stable soil environment, but this is less true of leys in mixed farming systems that are subject to frequent cultivation and disturbance. Much of the information about nitrate leaching from grassland has been derived from studies on long-term pastures but a number of experiments have indicated that less nitrate is lost from recently sown swards than from these older pastures (Scholefield *et al.*, 1993; Cuttle *et al.*, 1998). The processes by which pasture age influences nitrate leaching are not fully understood. Where grass is sown after a period of arable cropping, the reduced leaching may in part be attributed to the lower soil organic matter content and nitrogen (N) mineralization than under longer-established swards. This is a less satisfactory explanation where grass is resown immediately after cultivation of a previous grass sward. In those circumstances, ploughing will redistribute N and organic matter in the profile, but the total content in the soil should be little different from that before ploughing. Indeed, other studies have suggested that reseeding of grassland results in increased N mineralization and herbage production (Hopkins *et al.*, 1990) which would be expected to increase the risk of nitrate leaching. Understanding of the changes that occur in reseeded pastures is necessary for predicting nitrate leaching from short-term leys and in describing the N economy of crop rotations in mixed farming systems. We have examined the hypothesis that less N is leached from reseeded grassland because less soil N is mineralized in the initial years after reseeding than in long-term pasture. This results in less herbage production, lower stocking rates and, ultimately, in fewer urine patches, which are the main source of leached N in grazed grassland.

Material and methods

A field experiment was carried out at the IGER Research Farm at Trawsgoed, near Aberystwyth (Grid ref. SN 672 741) to investigate nitrate leaching from recently sown leys and long-term grassland. A series of 18 plots (6 m × 2.2 m) was established in an area of permanent pasture that had been fenced to exclude stock. The existing pasture had been sown in 1986 with a perennial ryegrass (*Lolium perenne* L.) - white clover (*Trifolium repens* L.) mixture. At the start of the experiment, ryegrass remained the dominant species with only a trace of clover. Soils were freely drained brown earths (Dystric cambisols) of the Rheidol series (Rudeforth *et al.*, 1984). Six plots were allocated to each of three treatments. Starting with a similar sward on all plots, the treatments were subjected to different management practices in 1995 and 1996 to prepare three contrasting swards for study in 1997-98:

(*i*) Permanent pasture (uncultivated);
(*ii*) Grass sown in 1996 directly after cultivation of the original pasture;
(*iii*) Grass sown in 1996 after two barley crops.

The six plots allocated to the arable treatment were rotovated to 15 cm depth in May/June 1995 and sown with barley. No N fertilizer was applied. The barley was harvested in September and the plots cultivated before leaving fallow over the winter. A second barley crop was sown in March 1996 with 20 kg fertilizer-N ha^{-1} and harvested in August. During this period, the remaining plots were left as the original sward and were cut at intervals. They received 160 kg fertilizer-N ha^{-1} in 1995 and 300 kg ha^{-1} in 1996. In late August 1996, the plots allocated to the reseeded grass treatment were cultivated by hand, inverting the turf to simulate ploughing to 15 cm depth. These plots and the barley plots were then resown with perennial ryegrass (cv. Aber Silo). The remaining six plots were left undisturbed as the original sward. After re-establishing the grass swards, all plots were managed similarly. Plots received 210 kg fertilizer-N ha^{-1} in 1997 and were harvested at intervals for determination of herbage yields and N contents. Four of the plots in each treatment contained ceramic cup samplers for measurements of nitrate leaching. Samplers were installed to collect water from 0.6 m depth with four samplers per plot. The remaining two plots within each treatment were used for destructive sampling to determine soil mineral-N contents at intervals during the growing season. In addition, in July and August 1997, microplots (0.5 m × 0.5 m) within these plots were treated with ^{15}N-labelled fertilizer to distinguish between the uptake of fertilizer and soil N. In January 1998, an intact soil block was collected from each of these microplots and sectioned into 0 - 6, 6 - 12, 12 - 18 and 18 - 24 cm depths. Soils from the different depths were mixed with sand, adjusted to an optimum moisture content and incubated aerobically at 30 °C in the laboratory to determine potential rates of net N mineralization.

Results and discussion

Detailed monitoring was confined to the 1997 growing season and following winter. However, soil water samples were collected in the preceding two years to examine the effects of the cultivation pretreatments on nitrate leaching from what would become the reseeded grass and arable plots. As would be expected, nitrate concentrations in water samples from the fallow plots after the first barley crop in 1995 were appreciably higher than from the undisturbed grass sward (Figure 1). These plots and the reseeded grass plots were resown with grass in autumn 1996, but the sown swards provided only sparse ground-cover during this first winter and nitrate losses from these plots were again much higher than from the undisturbed sward (Figure 1).

There was rapid growth and tillering of the reseeded grass plots in the following spring, so that by the first harvest at the end of April, dry matter yields were not significantly different from those for the permanent pasture plots. Only at one harvest there

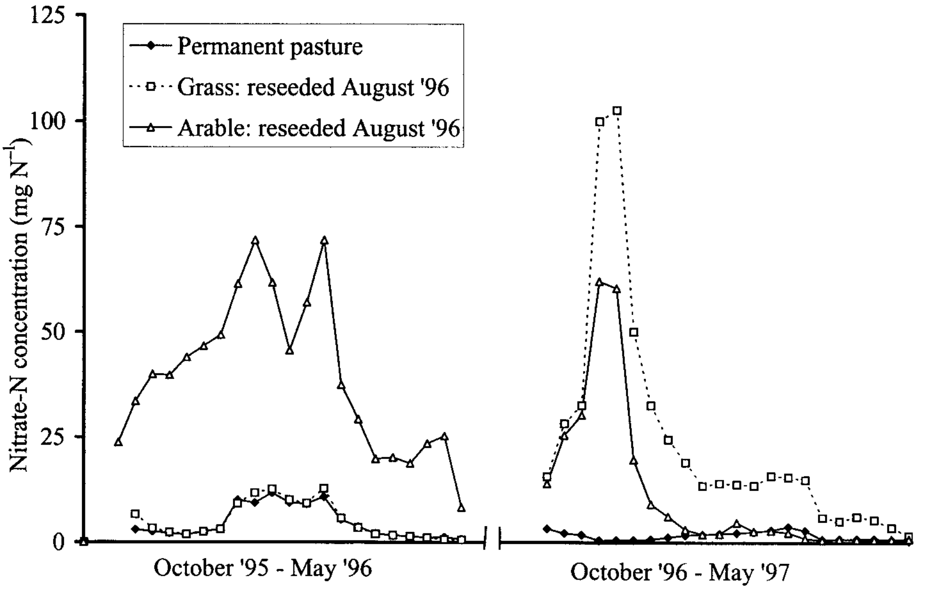

Figure 1. Mean nitrate-N concentrations in soil water from permanent pasture plots and from resown grass plots after cropping with barley in 1995-96 or after cultivation of pasture in 1996.

was a significant difference between the yields from the different swards: on this occasion yields from the two reseeded treatments were higher than those from the permanent pasture. Total dry matter yield between March and October 1997 did not differ significantly among the three treatments (Table 1). In contrast, the results demonstrated that the cultivation and reseeding treatments increased mineralization rates in the soil. The quantity of N taken up by the sward was used as a measure of available soil N. At all harvests, herbage from the permanent pasture plots contained higher contents of N than either reseeded arable or reseeded grass plots ($P<0.01$). Similarly, total N uptake by herbage between March and October on the permanent pasture plots was significantly higher ($P<0.001$) than for the reseeded arable or reseeded grass plots (Table 1). Contents of mineral-N in the 0 - 8 cm soil depth, sampled at intervals during the growing season were also greater in the permanent pasture plots than in either of the reseeded treatments, providing further evidence of greater release of N in the permanent pasture. There was no accumulation of mineral-N in the soil of the reseeded plots to indicate that the lower N contents in the reseeded plots arose because the resown variety was any less efficient at utilizing soil N than the grasses present in the original long-term pasture. The uptake of ^{15}N by the herbage from the microplots that received labelled fertilizer allowed a distinction to be made between uptake from fertilizer and soil-N. Results from both treatment dates confirmed that the higher N uptake on the permanent pasture plots arose from greater availability of soil-derived N rather than from differences in the efficiency of fertilizer utilization (Table 1).

Table 1. Total yield of herbage and uptake of N from permanent and reseeded swards between March and October 1997 (mean ±SE) with the uptake of soil-derived N in the four weeks following application of ^{15}N-labelled fertilizer in July.

Sward type	Total herbage yield (kg DM ha^{-1})	Total N uptake (kg ha^{-1})	Uptake of soil-N (kg ha^{-1})
Permanent pasture	13261 (±268)	377 (±8.8)	54.5 (±4.53)
Grass reseed	13281 (±175)	313 (±7.3)	36.9 (±0.90)
Arable reseed	12901 (±353)	303 (±11.8)	40.4 (±1.70)

Table 2. Potential rates of net N mineralization (mean ± SE) in soils from different depths from permanent and reseeded pastures as determined under laboratory conditions.

Soil depth	Net N mineralization (g m^{-2} d^{-1})		
	Permanent pasture	Grass reseeded	Arable reseeded
0 - 6 cm	0.33 (±0.037)	0.18 (±0.010)	0.25 (±0.036)
6 - 12 cm	0.19 (±0.025)	0.25 (±0.020)	0.26 (±0.012)
12 - 18 cm	0.19 (±0.028)	0.22 (±0.022)	0.21 (±0.013)
18 - 24 cm	0.14 (±0.019)	0.15 (±0.006)	0.15 (±0.012)
Total	0.85 (±0.090)	0.80 (±0.038)	0.87 (±0.063)

Concentrations of nitrate in drainage water during winter 1997-98 were low under all three treatments and did not exceed 2 mg N l^{-1} (Figure 2). Between October and January, nitrate concentrations in drainage water from the permanent pasture were consistently higher than those from the reseeded arable plots, but these differences were not statistically significant. Concentrations from the reseeded grass plots were higher than those from the reseeded arable plots throughout the winter, and up to January were similar to those from the permanent sward. The differences between treatments were small compared with the impact of cultivation on nitrate losses in the previous years. In the absence of grazing, pasture age appeared to have little effect on the quantities of N leached.

Examination of N mineralization in the soil cores collected from the permanent pasture plots in winter 1997-98 showed a reduction in the rate of net mineralization with increasing depth (Table 2). In the case of the reseeded plots, total mineralization was similar to that in the permanent pasture soil but a greater proportion of the activity occurred at the lower depths. In the reseeded arable plots, organic matter from the old sward had been thoroughly mixed throughout the cultivated layer over two years of cropping, whereas in the case of the reseeded grass plots, the plough layer had been carefully inverted to keep the surface root mat intact. In spite of this, there was relatively little difference in the distribution of mineralization and respiration activity in the two reseeded treatments. One year after cultivation, mineralization in the reseeded grass soil was evenly distributed among the top three sections with no evidence that the buried root mat in the 12 - 18 cm depth was the

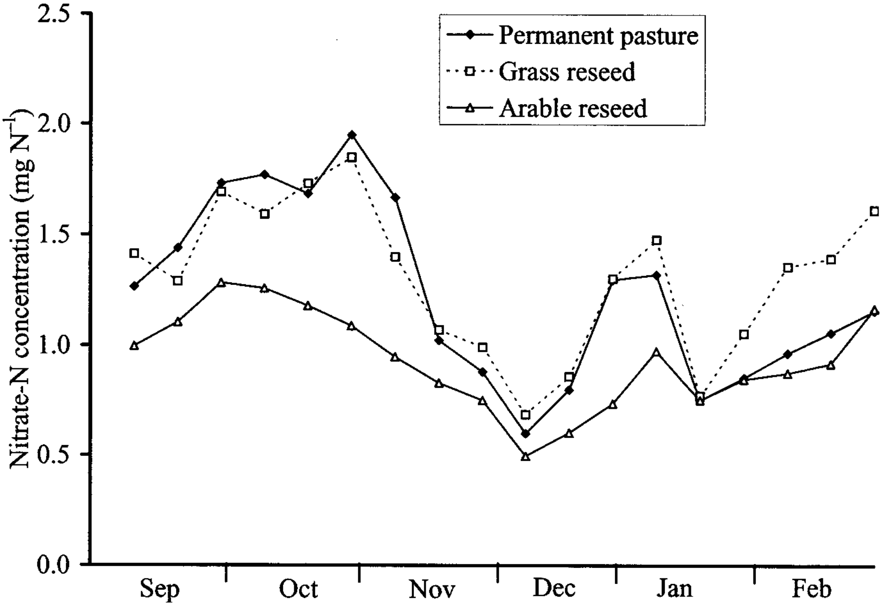

Figure 2. Mean nitrate-N concentrations in soil water from permanent pasture and resown plots in winter 1997-98 after re-establishment of the grass swards.

main site of N release. The laboratory determinations provided no explanation of the different mineralization rates observed between reseeded and permanent pasture plots in the field. The value provided by the laboratory incubation is a measure of the potential rate of mineralization under optimum conditions. If, in the field, soil physical conditions below about 6 cm depth are less favourable for mineralization than in the surface soil, this would have a greater impact on the release of N in reseeded soils, as a larger proportion of the potentially mineralizable N was present in these deeper sections.

The hypothesized mechanism by which reseeding is thought to influence N leaching involves a series of assumptions. The first of these, that less N is mineralized in recently reseeded pastures, is supported by the results of the present investigation. Less N was mineralized in the reseeded plots than in the permanent pasture, irrespective of whether the plots had previously been cropped with barley or were reseeded directly from fertilized grass. The further hypotheses require that the lower rates of mineralization should in turn result in less herbage growth, reduced stock-carrying capacity and fewer urine patches to contribute to N losses. Under the conditions of the current experiment, herbage yields from the reseeded plots were similar to those from the permanent sward in spite of there being less N mineralization. All three pastures would be expected to support similar numbers of stock and the area affected by urine would be expected to be similar in all three cases. The results therefore do not support the initial hypothesis but they do indicate an alternative mechanism. Herbage on the reseeded plots contained lower concentrations of N and animals grazing on these swards would therefore be expected to excrete less N in their urine. In these circumstances, less N would be available for leaching from recently reseeded pastures because of lower concentration of N in individual urine patches, rather than because of a reduction in the overall area affected by urine.

Acknowledgements

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Mixed farming, consequence for soil fertility

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Introduction

In Denmark, most farms are mixed farms either with cows or pigs. State regulations determine how many animal units a farmer can have per unit area. For pigs it is allowed to have 1.7 animal units per hectare and for cows 2.3 animal units per hectare. In Denmark, an animal unit is defined for cows and pigs to be 6000 feed units metabolized with the corresponding total amounts of nitrogen (N), phosphorus (P) and potassium (K) in the manure (Poulsen & Kristensen, 1997). For cows, one animal corresponds with a production of 17.7 tons of manure containing 128 kg N, 23 kg P and 100 kg K. In 1999, the regulations will change; then, 100 kg N produced in manure will be the level for one animal.

Mixed farming systems with animals will, in the long-term, enrich the soil with organic matter. In fodder crop rotations, up to: 75% of the area will be covered with grass or clover-grass mixtures, and fertilization will be by animal manure, with a high input of organic matter of a high nutritional status for decomposition by soil fauna/flora organisms and it is very difficult to design crop rotations that are able to keep nitrogen (N) in the crop/soil environment and thereby prevent leaching. Measurement of leaching on such farms has under Danish conditions shown losses of nitrogen up to 400 kg ha^{-1} (Grant, 1997).

On farms producing pigs, there is much less input of organic matter. Organic matter input is only from two sources: straw mulching and animal manure. Not many Danish pig farmers use catch crops to prevent leaching. It is a problem for pig farmers to conserve nitrogen in the soil, because of the cereal-dominated crop rotations. The increasing area of winter wheat on these farms creates leaching losses, because it is necessary to plough early and sow wheat before October. In autumn, winter wheat is able to take up only about 15 kg N ha^{-1} and ploughing itself will under these conditions, on farms with animals, release much more N than this amount. Under Danish climatic conditions, this will result in N leaching. A strategy for these farms could be to introduce catch crops and use them where possible in the rotation for conserving nitrogen, and thereby increase soil fertility in relation to fertilization.

This article focuses on the input of organic matter from straw, manure and catch crops and their effect on yield in a complete rotation.

Method

At Research Station Jyndevad, situated on a coarse sandy soil in the south of Jutland, a

Table 1. Relative yields (no input of organic matter is set at 100). Yields refer to main crops only.

Organic matter treatments	Av. 9 yrs Potatoes	Av. 9 yrs Barley	Av. 5 yrs Barley	Av. 4 yrs Oats	Av. 9 yrs Rye	All
1. No org. matter input	100.0	100.0	100.0	100.0	100.0	100.0
2. Straw, catch crop	107.1	111.9	83.0	96.4	104.6	100.6
3. Straw, catch crop, manure	100.0	98.5	72.1	80.5	94.4	89.1

project with various inputs of organic matter was started in 1988. The crop rotation is:

- Potatoes,
- Winter rye,
- Spring barley with catch crop (from 1988 to 1992), changed to oats with catch crop (from 1993 onwards),
- Spring barley with catch crop.

In this rotation, three different input levels of organic matter have been run since 1988. The three organic matter levels are replicated three times. In organic matter level *one*, all straw is removed from all crops except potatoes and fertilization is by industrial fertilizer only. Catch crops are not used. In organic matter level *two*, all straw from crops is retained in the rotation, and mulched into the soil. Fertilization is by industrial fertilizer and catch crops are used where possible in the rotation. Up till now they have been used in spring cereals only. In organic matter level *three*, straw from all crops is mulched into the soil, catch crops are used and fertilization is by liquid manure from pigs. Yields have been measured in all plots.

The level of fertilization is the recommended level for each crop. For plots with liquid manure fertilization, the amounts of nitrate and ammonium of the manure are defined on the basis of plant-available nitrogen during the first growing season, and these amounts are adjusted to the same level as for industrial fertilizer. All crops are irrigated and pests and diseases are controlled by pesticides.

Results

Yields are measured since 1989 in all treatments and all crops in the rotation. From 1988 to 1992, the rotation contained two barley crops, but it became obvious that one of the barley crops could in advance be replaced by oats. Oat has some advantages over barley especially on this very sandy and less fertile soil. To get an overview, Table 1 summarizes yield results for nine years and only the last four years oats has been part of the rotation. The first five years it was barley.

Table 1 shows yield responses in relation to addition of organic matter as a function of fertilization by industrial fertilizer and removal of straw (100%). It shows that addition of straw, use of catch crops and fertilization by industrial fertilizer for all crops except barley (after barley) and oats, leads to higher or the same yield. When using liquid manure, instead of industrial fertilizer, yield is reduced, probably because it is not realistic to define the mineral part of manure as available completely during the growing season on this sandy soil, which has a very low capability to deliver N from soil reserves for crop uptake. The results also suggest that barley or oats do not benefit from the incorporation of straw into the soil from the previous rye crop. Rye produces most years double the amount of straw than the other crops in the rotation and N in the soil will be used to decompose straw, instead of being used for production. In Denmark, we have mild and rainy winters and it is, therefore, impossible to retain N in soil from one growing season to another; it will be lost through nitrate leaching in winter. Decomposition of straw will, therefore, in case of high amounts of straw, utilize nitrogen from fertilizer nitrogen.

Tables 2 and 3 show yields of potatoes and rye for the years 1989 to 1997. Especially potato yield shows a very classical response to addition of organic matter. In the first years of the rotation with addition of organic matter, yields decreased but after some years they

Table 2. Potato production (t ha^{-1}) for the years 1989 to 1997 and the index for these years.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	Mean
Yield potatoes										
No org. matter	47.0	52.6	47.8	48.7	53.7	39.5	34.0	40.1	38.5	44.69
Straw, catch crop	48.1	48.0	48.9	53.2	58.4	46.5	41.0	44.1	39.5	47.52
Straw, catch crop, manure	44.3	48.6	45.3	50.2	51.1	42.0	37.8	43.5	36.7	44.39
Index potatoes										
No org. matter	100	100	100	100	100	100	100	100	100	100
Straw, catch crop	102.3	91.3	102.3	109.2	108.8	117.7	120.6	109.2	102.6	107.1
Straw, catch crop, manure	94.3	92.4	94.8	103.1	85.2	106.3	111.2	107.7	95.3	100.0

Table 3. Rye production (t ha^{-1}) for the years 1989 to 1997 and the index for these years.

	1989	1990	1991	1992	1993	1994	1995	1996	1997	Mean
Yield rye										
No org. matter	-	4.79	4.49	3.66	4.83	5.80	3.85	3.08	4.73	4.40
Straw, catch crop	-	4.88	4.64	3.90	4.72	6.02	4.26	3.57	4.58	4.57
Straw, catch crop, manure	-	4.44	4.51	3.33	3.93	5.04	4.16	3.73	3.45	4.07
Index rye										
No org. matter	-	100	100	100	100	100	100	100	100	100
Straw, catch crop	-	101.9	103.3	106.6	97.7	103.8	110.8	116.0	96.8	104.6
Straw, catch crop, manure	-	92.7	100.4	91.0	81.4	87.0	108.2	121.2	73.0	94.4

increased and for most years yields are higher compared to the situation with removal of organic matter. Rye shows the same responses, but there is a larger variation between years.

Discussion

The various elements of an arable cropping system, such as crop type, soil tillage, use of fertilizers, crop residue management, crop rotation, etc., all interact in a complex manner with basic soil properties, and this interaction determines the overall productivity of the cropping system.

In developing systems based on low inputs, soil fertility is a key element and also illustrates how different strategies of farm management influence soil fertility. Soil fertility with respect to nutrients is its capability to supply nutrients from soil-borne reserves to plant production. Addition of organic matter influences these relations. Organic matter produced in agriculture has very different qualities for decomposition. Straw has a very low quality and needs nitrogen at the first step of decomposition. It is clear from the results that the large amount of straw from rye, immobilizes nitrogen from the soil, which is not able to supply nitrogen in the following growing season. In 1991, straw from rye was left on the surface. In spring, the soil was ploughed and immediately sown to spring barley. The results demonstrate that the decomposition immobilizes nitrogen from the soil. The yield decreased by 60%. Especially potatoes do benefit from addition of organic matter. It might be a combination of the right placement in the rotation and the advantage of a more stabile soil structure.

Utilization of manure has been discussed extensively in Denmark. In this project, the mineral part is defined to be available in the growing season. Many reports (e.g. Poulsen & Kristensen, 1997) state this and the only assumptions are even spreading and working it into the soil just after spreading. The guidelines for optimal handling of manure have been followed in this project. The conclusion is that we did not succeed in using manure in the most optimal way. The fertilization was by liquid manure from pigs and about 70% of the nitrogen was on mineral basis.

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Using models to optimize the efficiency of nitrogen use across whole farm rotations

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Introduction

Effective management of the nitrogen (N) cycle is an essential component of sustainable agriculture in Europe. Mathematical models can be used to simulate N transport in agricultural systems as a basis for optimizing efficiency of N use. In arable cropping systems, some rotations are inherently leaky, because of the differential rates of mineralization of crop residues, while in systems of animal production the feeding of N-rich forage and the need to dispose of manures give rise to inefficiency in N use. In both cases, integration of arable and grass in rotations could potentially increase overall N use efficiency.

The amount, type and timing of fertilizer applications may be iteratively adjusted to provide fertilizer recommendations that minimize N losses while maintaining productivity. However, because N held as organic matter in the soil can be mineralized and become available when the crop is unable to take it up, some rotations are inherently leaky. These losses cannot be reduced by improving fertilizer recommendations. The whole farm rotation must be designed so that the sequence of crops makes best use of the timing of N release in the soil. Mixed farming systems can offer greater diversity than each agricultural production sector separately, and so have a higher potential to reduce losses by optimizing the rotation.

A recent study on N losses in whole farm arable systems has led to the development of a novel technique for deriving optimum rotations (Smith & Glendining, 1996; Smith *et al.*, 1997). The system derives all rotations allowed within entered constraints, uses a dynamic ley-arable model to calculate total N losses and crop N offtake, and outputs the N dynamics for the best and worst case rotations. Imposing different policy options alters constraints on the allowed rotations, resulting in different N losses. The dynamic ley-arable model has been developed by linking the grassland NCYCLE model (Scholefield *et al.*, 1991) to the arable SUNDIAL model (Bradbury *et al.*, 1993; Smith *et al.*, 1996). Outputs from NCYCLE act as inputs to SUNDIAL, allowing complete ley-arable rotations to be simulated (Scholefield & Smith, 1996). The potential to increase N use efficiency is then calculated from the difference in N use efficiency of the best and the worst-case rotations.

The purpose of the work reported here is to examine the effect of different lengths of the arable phase in the ley-arable rotation on the efficiency of N use. Standard UK management practices are used to investigate systems currently in use in the field. All factors are held constant with the exception of the length of the arable phase.

Material and methods

The ley-phase of a rotation

The model NCYCLE (Scholefield *et al.*, 1991) which is the basis of the model used to simulate the ley-phase of a rotation, is an empirical, annual mass balance model. It comprises linked submodels derived from measurements of N flows and pools, subdivided in 10 grazing systems (Figure 1). The key submodel in NCYCLE uses a linear regression to partition the annual throughput of soil inorganic N between 'plant N' and the processes of N loss (ammonia volatilization, denitrification and nitrate leaching). The greater the throughput, the higher the proportion that is lost. Other important submodels are those that determine the annual additions of N to the soil inorganic pool due to management, soil physical conditions and climatic zone. The proportion of 'plant N' that is ingested by grazing animals may be adjusted continuously according to grazing pressure, but defaults to 62%, a value determined using the best available data for good grazing management. Ingested N is then partitioned between 'product N', which is exported from the system, and 'dung N' and 'urine N' that are returned to the organic and inorganic soil N pools, respectively. The N that is deemed to be lost is partitioned as follows: first, N volatilized as ammonia is subtracted at 15% of 'urine N' plus 3% of 'dung N'; then N lost through denitrification is calculated from coefficients based on soil texture and drainage status, and subtracted to leave that potentially leached as nitrate. The annual accumulation of N in organic components is calculated from the sum of 'dung N' and 'dead N', which is one of the two output variables from the ley-phase model to be passed as input variables to the arable phase model. The other output variable in this category is the leachable N generated in the final year of the ley-phase. A major recent development of the NCYCLE model has been the addition of submodels to describe N_2-fixation by white clover in grass clover swards (Scholefield *et al.*, 1995). The new submodels describe the effects of three important mechanisms: (*i*) the inhibitory effect of soil inorganic N on N_2-fixation, and thus the proportion of clover N originating from the soil; (*ii*) the direct and indirect transfer of clover N to soil via senescence and grazing, and (*iii*) the effects of grazing preference on the proportion of clover in the sward.

The arable-phase of the rotation

The model SUNDIAL (Bradbury *et al.*, 1993; Smith *et al.*, 1996) which is the basis of the model used to simulate the arable-phase of the rotation, is a dynamic model, incorporating descriptions of all major processes of N turnover in the soil/crop system on a weekly basis (Figure 2). Unlike many other N models, N dynamics in SUNDIAL are driven by the carbon (C) cycle. Nitrogen may be added to the soil/crop system as inorganic fertilizer, organic manure or atmospheric deposition. Nitrate and ammonium are taken up by the crop in proportion to its expected yield and the cumulative temperature since sowing. Nitrogen and C are then returned to the soil, not only at harvest as stubble and straw, but also throughout the growing season as root exudates, dead leaves and dead root material. Decomposition of crop debris is represented by partitioning the C and N into biomass and humus according to soil type. The C:N ratios of these organic matter pools are assumed to remain constant. If the C:N ratio rises, due to a higher C:N composition of the crop debris, N is immobilized first from ammonium and then from nitrate in the soil. If the C:N ratio falls, N is mineralized to ammonium. Ammonium may then be nitrified to nitrate, which subsequently may be lost by denitrification or leaching.

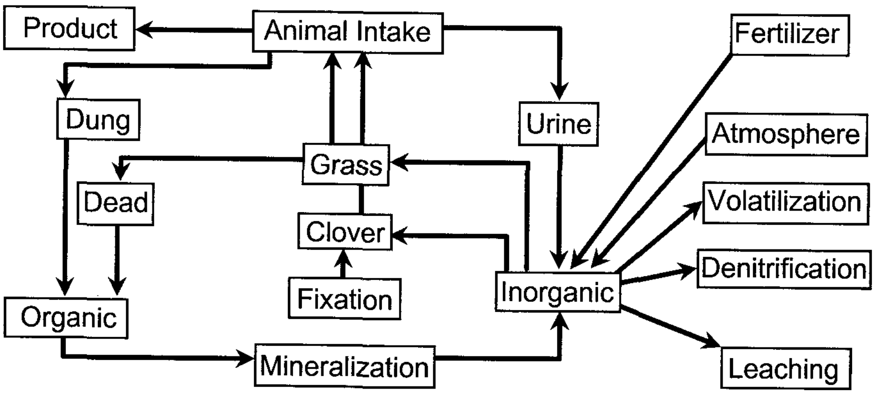

Figure 1. The NCYCLE model.

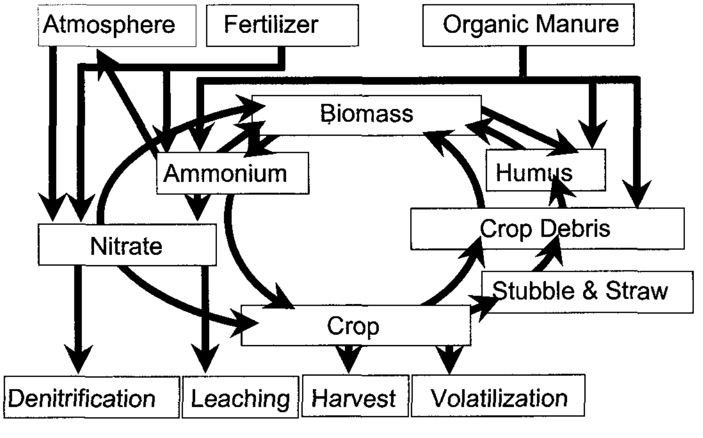

Figure 2. The SUNDIAL model.

Ploughing-in of grassland

The potential of the soil organic matter residues remaining after the grass ley to release mineralized N may be simulated within SUNDIAL by partitioning carbon and N from the residues into microbial biomass and humus pools. Because the C:N ratio of these pools determines the rate of soil organic matter decomposition, appropriate partitioning of residue carbon and N allows observed decomposition rates to be reproduced. Measurements of mineral N remaining in the soil following ploughing-in of leys of different ages and compositions (such as described by Johnston *et al.,* 1993) were used to interactively adjust the partitioning parameters to give the best-fit between simulated and measured mineral N levels in the soil. The completed model was then evaluated against independent data. Evaluations of model performance will be discussed elsewhere. The completed ley-arable model was then able to simulate ley-arable rotations using NCYCLE and SUNDIAL sequentially.

Optimizing the efficiency of nitrogen use

The decision-support system described by Smith & Glendining (1996) and Smith *et al.* (1997) was used to identify the rotation that makes best use of available and applied N, given standard timing and rates of fertilizer applications. This system uses a *scenario generator* to identify all rotations of crops allowed within the imposed set of farming rules. The status of the farm is defined within the system by selecting the minimum allowed length of rotation (in years), the proportion of land allocated to a particular crop, and any constraints imposed on farm management. The system calculates all possible combinations of crops that may result in the required cropping ratio, removes any rotations not allowed within the constraints identified, and uses the ley-arable model described above to calculate the N dynamics of all remaining permutations. All rotations meeting the identified criteria for optimum management are saved and the N dynamics associated with each rotation presented.

The effect of the number of years between ley-phases on efficiency of N use in low, medium and high input systems was investigated using standard inputs from current UK fertilizer recommendations (MAFF, 1994) and crop statistics for England and Wales (Nix, 1995; Soffe, 1995). Low, medium and high inputs to the ley-phase were assumed to be 0, 200 and 400 kg N ha^{-1} yr^{-1}, respectively. The arable phase was entered as continuous wheat: it was assumed that problems such as build-up of disease in subsequent wheat crops was avoided by chemical treatment. This somewhat unrealistic scenario was used so that the influence of the time lag between ley-phases could easily be separated from the effects of the stages in more complex arable rotations. The results were expressed as efficiency indices for sustainability, productivity and environmental impact (Scholefield & Smith, 1996).

Results and discussion

The efficiency of N use within a ley-arable system is a function of inputs into the system, soil type, as well as the number of years under ley or arable management. Various expressions of efficiency of N-use have been derived relating to sustainability, productivity and environmental impact of the system.

Sustainability is indicated by the ratio of total N input to N removed in product and as losses to the wider environment. A ratio below 1 indicates that the system is undergoing net loss of N and so is not sustainable over the long-term. At all levels of productivity, introduction of an arable phase in the rotation results in an immediate reduction in sustainability (Figure 3). The sustainability of the system then gradually increases with number of years between ley-phases. Given standard management practices (MAFF, 1994), the ley-arable system appears to be more sustainable at high production levels. If fertilizer inputs had also been optimized within the decision support system, sustainability might have been improved for all levels of productivity.

Efficiency of the productivity of the system is indicated by the ratio of N in product to N input as fertilizer. A high ratio indicates a more productive system. At low and medium productivity levels, the efficiency of productivity of the system shows a steady decline with number of years in the arable phase (Figure 4). At high productivity levels, however, the efficiency of productivity shows a small increase with time in the arable phase. At high productivity, efficiency is higher in the arable than the ley phase, resulting in the observed increase. Overall, the system is more efficient at low productivity than high productivity levels, as a higher proportion of N is obtained from the soil reserves.

The environmental impact is calculated as the ratio of N losses to N in product. A high environmental impact indicates greater potential damage to the environment per unit of product. The environmental impact of the system increases up to 4 years after the start of the arable phase (Figure 5). Increasing the arable phase beyond 4 years results in a steady decline in environmental impact. Net mineralization of soil organic N residues, following the ley phase also increases in low, medium and high productivity systems up to 4 years of the arable phase, after which net immobilization is observed. The standard management practices used (MAFF, 1994) do not give sufficient weight to the supply of N from these

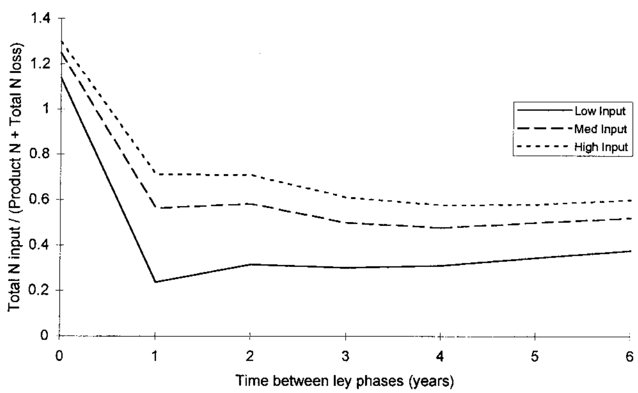

Figure 3. Sustainability – silt loam in Central Southern England.

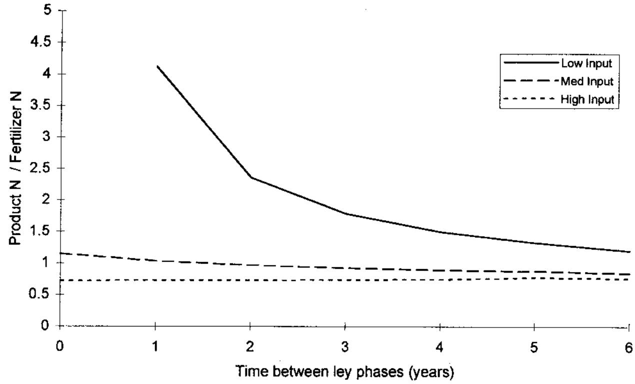

Figure 4. Efficiency of productivity – silt loam in Central Southern England.

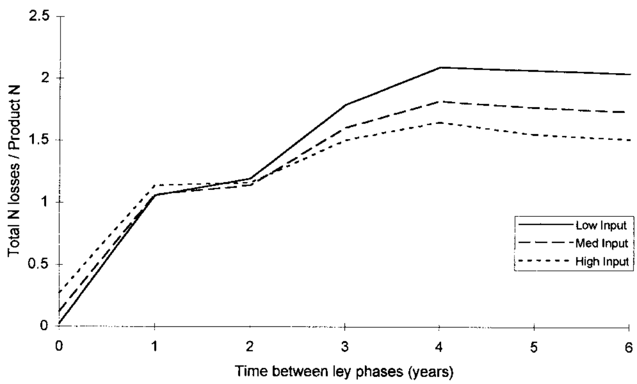

Figure 5. Environmental impact – silt loam in Central Southern England.

organic residues. Environmental impact could certainly be reduced at all productivity levels by also optimizing fertilizer applications to account for the additional N available from the organic residues in the soil.

Conclusions

The above results suggest that if standard management practices are used, a ley system is more efficient than a ley-arable system in terms of sustainability, productivity *and* environmental impact. As the length of the arable phase is increased to 6 years, the difference in efficiency of the ley and ley-arable systems decreases. This result is directly attributable to insufficient weight being given, in the standard management system chosen, to the supply of N from the organic residues of the ley-system. When planning ley-arable rotations, it is essential that the fertilizer inputs should be optimized to account for the very large potential for N supply from the ploughed-in ley-phase.

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Optimized rotation and nutrient management in Organic Agriculture: The example experimental farm Wiesengut / Hennef, Germany

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Introduction: Aims and principles of nutrient management in OA

Organic Agriculture (OA) pursues an organizational principle: to manage a mixed farm as much as possible such as an organism within a more or less closed system. Due to restricted purchase of fertilizers, OA has to deal with limited amount of nutrients. Nutrient management is, therefore, considered as the optimal combination of resources that are restricted or have to be released. Strategies must be adopted that make nutrients in the system internally available by achieving optimized utilization (e.g. via increased rooting depth and density, N_2-fixation and efficient nutrient absorption), or which keep nutrients potentially available in the long-term.

Nutrient management has been defined as a systematic target-oriented organization of nutrient flows (Köpke, 1993, 1995). The main nutrient flows are fixed for the long-term by organizing and optimizing the site-adapted crop rotation. Moreover, the whole production system demands implementation within its own local, ecological, socio-economic and cultural environment.

Material and methods

Generally, mixed farming comprises a design of diversified rotations, which fulfil these needs easier. Against this background, this contribution deals with selected scientifically based steps of designing and optimizing a 6-field rotation at the Wiesengut experimental farm, focussing mainly on nitrogen (Table 1).

Results and discussion

Rotation design: Suitability of crops and crop positioning

The rotation has to maintain and possibly increase soil fertility, soil organic matter (SOM) and soil structure in the long-term. Positive pre-crop or residual effects are realized, depending mainly on nitrogen (N) availability as a function of the optimized crop rotation.

The *grass-clover ley* is the cornerstone for successful organic farming under conditions of humid (maritime) temperate climates. Here clover is grown, instead of lucerne, which is preferred in continental climates. In organic mixed farms with cattle, forage legumes and grasses constitute the basic crops in arable fodder cropping. Although the amount of N originating from biological N_2-fixation (BNF) is higher when pure clover is grown, mixtures with grasses facilitate silage making, with minimal adverse effect on

Table 1. Wiesengut experimental farm: steps to optimize crop rotation. Location: 50°48'N, 7°17'E; 160 m above sea level; 780 mm annual rainfall; 9.8 °C average annual temperature; sandy loam soil with gravel layers (Fluvisol (FAO) or Udifluvent (USDA)); 6 plots in 42 ha arable inner dam area; 20 ha grassland outer dam area. Options: potatoes, red clover, winter wheat, winter rye, faba beans, spring wheat, vegetables (kale); Undersown catch crops: Cruciferae; Livestock: suckler cow herd (Limousin), 1.0-1.2 LU ha^{-1}.

	STEP I —>	STEP II —>	STEP III —>	STEP IV
1	Winter rye undersown: Red clover	Winter rye undersown: Grass-clover	Winter rye undersown: Grass-clover	Winter rye undersown: Grass-clover
2	Red clover	Grass-clover mixture	Grass-clover mixture	Grass-clover mixture
3	Winter wheat	Oats	Potatoes	Potatoes
4	Faba beans	Faba beans	Winter wheat	Winter wheat stubble seed: Mustard
5	Potatoes	Potatoes	Faba beans undersown/stubble seed: Oil radish	Faba beans undersown/stubble seed: Mustard
6	Oats	Winter wheat	Oats	Spring wheat

fermentation, and reduce the surplus of N in the ration.

The higher the percentage of clover in the mixture and the yield per cut, the higher the amount of BNF. Lasting soil fertility must be based on the replacement of SOM. The most efficient and sustainable way to restore soil humus content is through the application of (composted) farm yard manure (FYM). The quantity of FYM applied has been used as a reference unit to quantify the replacement of SOM (Asmus, 1992). A sufficient quantity of grass-clover-mixture with high amounts of shoot and root residues will also restore SOM and will close the nutrient cycle (Table 2). Much of the nitrogen fixed by legumes is returned to the soil. In terms of SOM, one year of grass-clover can balance one year of humus-consuming non-legume root crop cultivation (Asmus, 1992). Therefore, organic crop rotations rely heavily on the cultivation of herbage legumes and grasses. This in turn constitutes another argument in favour of mixed farms.

At Wiesengut, the grass-clover mixture is sown in early spring using *winter rye* as a nurse crop. Growing *potatoes* as the first arable crop after ploughing up grass-clover in early spring, can avoid the substantial leaching losses that might occur on light soils during winter when grass-clover is ploughed in autumn to sow winter wheat as the first arable crop. Using this strategy, the duration of the period of soil tranquillity is extended by six months, or one third of the whole rotation, resulting in benefits for earthworms, increased air-filled pore space and less soil resistance for root penetration by subsequent crops. Compared to *oats*, potatoes can utilize the residual fertility of grass-clover more efficiently. Increased application of FYM to potatoes, corresponding to 0.6-1.4 LU ha^{-1} FYM, did not increase potato yields significantly (Stein-Bachinger, 1996). If substantial losses of

Table 2. Annual dry matter production (t ha^{-1}) and production of farm yard manure (FYM), balances of N and soil organic matter (SOM) (rotation: 6 fields of 7 ha each, 20 ha pasture, 62 LU, i.e. 1 LU ha^{-1}).

	Area (ha)	Harvestable yield (t ha^{-1})	Straw (t ha^{-1})	Fodder (t ha^{-1})	N (kg ha^{-1})	SOM (ROS* units) (t ha^{-1})
1. Winter rye	7	4.0	3.0	0.4	−50	−1.8
Underseed						+1.9
2. Grass-clover ley	7	12.0		12.0	+190	+5.6
3. Potatoes	7	5.0		0.5	−60	−4.9
4. Winter wheat	7	4.0	4.0	0.4	−70	−1.8
catch crop						+0.4
5. Faba beans	7	3.5		3.5	+165	+0.9
catch crop						+0.4
6. Spring wheat	7	5.0	4.5	0.5	−95	−1.8
Total rotation	42		80	121	+80**	−1.1***
Total pasture	20			140	+75**	
Total fodder				261		

−1.1 t ha^{-1} SOM (ROS units) needs 5.5 t FYM to be balanced (Asmus, 1992).
Fodder LU^{-1} 261×10^3 kg / (62 LU × 365 d) = 11.5 kg DM d^{-1}
Straw LU^{-1} 80×10^3 kg / (62 LU × 250 indoor feeding days) = 5.2 kg DM d^{-1}
Production of FYM LU^{-1} is 7.56 t rotten FYM
Surplus of 2.06 t FYM (7.56 – 5.5 t FYM) will increase SOM and soil fertility.

* ROS units refer to Asmus (1992); ** kg ha^{-1}; *** t ha^{-1}.

nitrate can be avoided after potatoes, *winter wheat* can profit significantly from indirect and direct pre-crop effects of the grass-clover mixture and potatoes. In contrast to potatoes, direct application of FYM to winter wheat as the second arable crop after grass-clover mixture increased grain yield significantly. A higher grain number can cause dilution of the limited available nitrogen, resulting in lower grain protein content. Application of liquid manure (50 kg NH_4-N ha^{-1} at growth stage EC31) can maintain or increase gluten content and baking quality (Stein-Bachinger, 1996). Field trials have shown that so-called nitrogen efficient cultivars of winter wheat have give yields but are still not chosen at the farm level.

Besides directly applied farm-produced manures, optimization of nitrogen flows is achieved by BNF and via adequate sinks for nitrogen in non-legumes. In pulses, BNF is closely correlated to grain yield and the amount of N in the grains (Köpke, 1987/1996; Hauser, 1992). The greatest amounts of fixed N can be obtained by selecting those species and cultivars that are best adapted to the given site conditions. All other cropping strategies resulting in higher grain yields will automatically increase BNF in pulses. Compared to peas, *faba beans* can compete better with weeds. Four tons ha^{-1} grain yield is equivalent to

160-200 kg N ha^{-1} symbiotically fixed N. The net gain of N for the farm is maximized by feeding the grains rather than by selling them. The residual fertility effect of faba beans is generally high. A mean fertilizer nitrogen equivalent of about 100 kg N ha^{-1} has been observed on loessial soils (Köpke, 1987/1996). Due to low rooting densities and heterogeneous root distribution, pure stands of faba bean leave behind high amounts of residual and soil-borne N before winter, which are susceptible to leaching. A 43% higher and more homogeneous rooting-distribution via narrow row distances reduced the nitrate gradient typical for wide rows, between the rows and directly under the rows. Intercropping with cereals considerably increased crop root length density, reduced soil residual-nitrate content but reduced faba bean grain yield, BNF and the residual fertility (Justus & Köpke, 1995). This strategy might be used in the future, when soil fertility has been improved further. Then the intercropped cereal may act as a sink for the higher amounts of soil-borne N, simultane-ously protecting the faba beans from aphids (Justus, 1996). Temporary N-immobilization caused by the high C/N ratio of cereal residues can limit the production of soil-borne nitrate.

Brassica species as underseeded or stubble crops in faba beans were the most efficient species, reducing soil nitrate content by up to 90%, but not reducing BNF. Up to 80 kg N ha^{-1} were taken up by *Brassica* species resulting in increased grain yields in subsequent oats or *spring wheat* of between 0.5-2.0 t ha^{-1}. Since grains produced by oil-radish can cause problems of volunteer oil-radish in following crops, white mustard is preferred either undersown or grown as a stubble crop.

The problem of accumulated surplus of nitrate

Besides sufficient amounts of symbiotically fixed nitrogen, sustainable soil fertility in OA is based mainly on optimal and increased production of SOM. Self-reliance regarding humus production is based on the cultivation of crops producing high amounts of roots and shoot residues and the application of FYM. Nitrogen balance and SOM balance of the above-mentioned rotation were calculated as positive and slightly negative, respectively (Table 2). Increasing the amount of SOM results in higher total C- and total N -contents of the soil. Increased mineralization rates (e.g. caused by optimized soil structure) or even unchanged rates result in higher soil nitrate contents. The extended soil nitrate pool can increase nitrate losses when plant sinks, i.e. efficient and sufficient nitrate uptake by plants, are inadequate. Implemented strategies to use *Brassica* underseeds or catch crops act merely on a temporary basis. Uptake of N by main crops is often limited as a result of non-synchronized availability of plant available N and limited N sink of the shoots. Serious problems of efficiency of N management exist after potatoes in particular. High amounts of soil nitrate after potatoes are caused by early senescence (often enhanced by *Phytophtora*) and several weeks of nearly bare soil, especially when late potato varieties are grown. Late harvests, combined with unavoidable intensive soil loosening further increase soil nitrate content and hinder proper timing of sowing catch crops. Therefore, currently a combined strategy of early N uptake and creation of a soil environment of immobilization is developed, by using crops with different composition of plant material. First results with

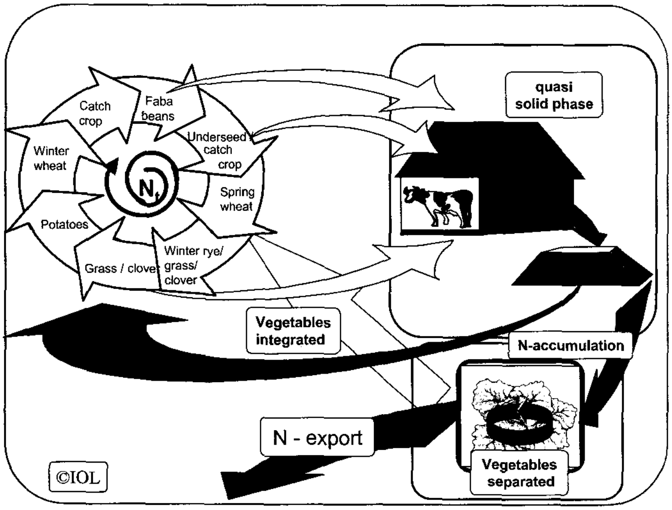

Figure 1. Efficient export of nitrogen via cultivating vegetables. N_t is total soil N content.

e.g. early sown maize, sunflower, marrow stem kale, appeared promising (G. Haas, unpublished).

All the suggested strategies become suboptimal, when the soil nitrate pool is steadily increasing. Alternatively, part of the nitrogen in the liquid phase may be stored in a more stable form in the solid phase via transferring, for instance, *Brassica* catch crops as forage crops via indoor feeding, to FYM (Figure 1). FYM can immobilize N in solid, less reactive N compounds – a strategy which can be used in mixed farms. Nevertheless, theoretically also this strategy is only partly effective in the long-term. The highly effective sink capacity of *Brassica* catch crops can focus attention on *Brassica* cash crops grown as vegetables, realizing high exports of N when sold. Two strategies of growing vegetables, integrated or as part of the rotation have to be investigated. It is assumed that rotation-integrated vegetable production is optimal for all conditions, in which case, based on site and rotation, the need for increased SOM would be high all over the farm. For farms having conditions of high soil fertility, i.e. with high N mineralization rates, the concept of 'external-rotation' production (separate vegetable production) should be considered. Here the liquid phase of nitrogen is drained by inner-farm export of nitrogen via the stable to vegetable fields in a separate rotation of vegetables (Figure 1).

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Nitrogen leaching losses from mixed organic farming systems in the UK

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Introduction

Food production according to organic standards (UKROFS, 1991) relies on plant nutrient supply through management of biologically regulated processes within a rotation (Hatfield, 1993). In the UK, organic farming systems are primarily based on mixed ley-arable crop rotations that allow nutrients to be recycled within the farm. The ley-arable crop rotation offers an opportunity to use nitrogen supplied by biological fixation to support animal production and subsequent arable cropping (Watson *et al.*, 1996). Within such rotations the relative proportion of ley and arable land are not only a fundamental determinant of total N input, but also critically affect the character of livestock production and the amounts of farmyard manure produced (Younie *et al.*, 1996). Although reliance on external inputs is reduced in organic systems, losses of nutrients still occur, primarily following the cultivation of leys to arable production (NRA, 1992). This paper presents nitrogen leaching data from mixed organic farming systems in the UK and examines whether such systems are able to meet the requirements of the EU directive (80/778) on water quality (EU, 1980).

Material and methods

Data have been derived from case studies from a range of geographic locations comprising a range of soil types, climatic and farming conditions.

EFRC - Farm monitoring programme

The Elm Farm Research Centre (EFRC) undertakes research, development and education in the fields of organic agriculture and appropriate technology. As part of its research programme, a farm monitoring programme of N leaching losses was carried out between 1993 and 1996. Three commercially operating organic farms were selected for monitoring with similar underlying geology and winter rainfall to pilot farms in UK Nitrate Sensitive Areas (Table 1) (MAFF, 1993). All fields on the organic farms were in ley-arable rotations, giving a total of 32 site years of ley-phase and 34 site years of arable cropping. Total length of organically managed rotations operated by the farmers ranged from four to seven years. Ten porous cups were installed in each field according to the method of Lord & Shepherd (1993).

Table 1. EFRC and OFS Study-Farm description: soils, geology, rainfall, livestock and organic rotations.

Farm[1]	Soil Texture[2]	Soil Group[3]	Geology	Grid Ref.	Rainfall[4] ($mm\ y^{-1}$)	Livestock	Farm rotation
1 (Wilts.)	Silty loam over chalk	Wantage	Chalk	SU 14 56	702	sheep, pigs, suckler beef	2 yr red clover set-aside; winter arable; spring arable
2 (Shrops.)	Sandy loam	Bridgenorth	Triassic sandstone	SJ 49 23	652	dairy, sheep	3 yr white clover; winter wheat; winter or spring oats
3 (Gloucs.)	Clay loam	Elmton	Jurassic limestone	ST 85 97	825	dairy, sheep, beef	3 yr white clover; winter wheat; spring cereal; spring beans; spring cereal

[1] Closest NSA (Nitrate Sensitive Area): Farm 1, Ogbourne St George; Farm 2, Tomhill; Farm 3, Old Chalford.

[2] From EFRC Analysis.

[3] Soil Association from Soil Survey of England and Wales

[4] Average annual rainfall (1960-1990). Derived from single site MORECS data.

Organic Farming Study (OFS)

As part of a multidisciplinary study of the economic, ecological and agronomic sustainability of conversion to organic farming systems (Cobb *et al.*, 1998), a detailed study of nutrient flows was carried out at Farm 3 in the farm monitoring programme (Table 1). Sixty-nine porous cup samplers were installed in a rectangular grid array (10 m spacing) across one field, following cultivation of a five year grass-clover ley. The field contained three contrasting soil types (shallow clay loam, deep clay loam, deep sandy loam) whose boundaries had been mapped in detail.

To allow comparison of the environmental impact of organic and conventional farming systems, two model farms were designed (O'Riordan & Cobb, 1998). The farm manager was consulted and the conventional management was based on the system on conventionally share-farmed land. The organic system was based on management of the organic farm, following completion of conversion. The systems occupied the same land areas with similar enterprises. Nitrogen balances were compiled for all the fields, using the whole farm nutrient budget approach (Watson & Stockdale, 1998).

Sampling and analysis of porous cups

Water samples were taken at 14-days intervals throughout the drainage period and nitrate concentrations were determined colorimetrically. Total losses of nitrate by leaching were calculated using the trapezoidal rule (Lord & Shepherd, 1993), using an estimate of drainage derived from the Meteorological Office Rainfall and Evaporation Calculation System (MORECS) (Thompson *et al.*, 1991).

Table 2. Nitrate leaching (kg N ha^{-1}) from organic ley-arable systems measured using porous cups over the period 1993-96 (EFRC, 1997).

Previous crop	Crop in winter of measurement	Nitrate loss (kg ha^{-1})	Minimum	Maximum	Number of measurements
Arable	Grass 1	36	1	114	16
Grass	Grass	11	0	52	17
Grass	Arable	82	8	187	16
Arable 1	Arable 1	50	7	182	12
Arable 2	Arable 3	70	9	145	5

Results and discussion

N lost by nitrate leaching in organic mixed systems

The rotations on each of the farms varied both in length and crop type. Farm 1 had the shortest rotation of four years with equal proportions of ley to arable crops and from this rotation the average leaching loss was 40 kg N ha^{-1} yr^{-1}. Farm 2 practising a five year rotation, 3:2 ley to arable, produced an average leaching loss of 37 kg N ha^{-1} yr^{-1}. Farm 3 had the longest rotation of seven years with 3:4 ley to arable within average leaching loss from this rotation of 46 kg N ha^{-1} yr^{-1} (Table 2) (EFRC, 1997).

The loss is not uniform throughout the rotation. The transition from ley to arable cropping in the organic rotation is generally associated with the highest loss (Johnston *et al.*, 1994). In this study, the average loss from this phase over the three years was 82 kg N ha^{-1}. The ley-phases were associated with lower losses, the average loss, regardless of age, over the three years was 21 kg N ha^{-1}. However, it appeared that the method of establishment of new leys influenced the leaching loss in the first year, i.e. loss from undersown leys was 17 kg N ha^{-1} compared with an average of 66 kg N ha^{-1} when leys were established by drilling following cultivation to prepare a seedbed.

In a mixed organic farming system less than half the farmed area is cultivated in any one year, and only 10-25% of this is represented by the incorporation of the fertility building ley (NRA, 1992). Season, timing and intensity of cultivation of the ley can have a substantial effect on nitrate leaching (Philipps & Stopes, 1995). Rotations relying on the ley being cultivated in spring demonstrate a reduced risk of nitrate leaching. (Watson *et al.*, 1993; Philipps *et al.*, 1995). Spring cropping features in areas of the UK where conditions are not favourable for winter cereals (Watson *et al.*, 1996). However, in situations suitable for autumn cropping, winter cereals are more profitable. Here the challenge is to select a first arable crop that is as profitable as winter wheat and utilizes the released N efficiently. In second or subsequent arable phases of the rotation spring cropping is more common, and use of overwinter cover crops or stubbles further reduce leaching losses from these phases.

Data from EFRC (1997) showed that leys cultivated in July/August rather than late September or early October resulted in reduced weed growth, but increased leaching. However, the development of mechanical weed control strategies may enable farmers to

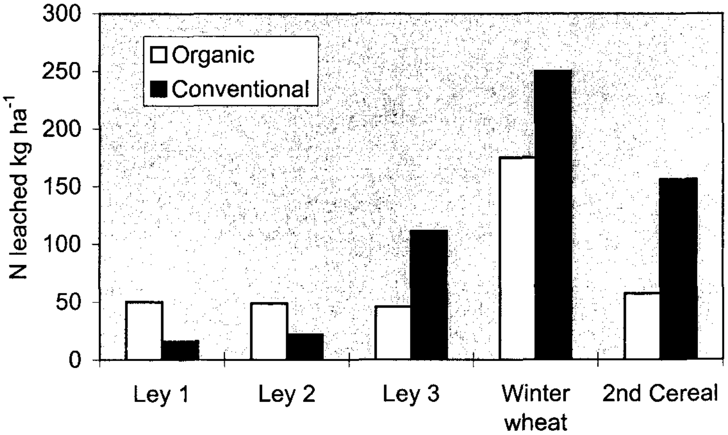

Figure 1. Comparison of modelled nitrate leaching losses from an organic mixed farm with losses from a conventional mixed farm.

adopt late ley cultivation practices. Although mechanical weeding increases mineralization, it is likely to be at a time of year when the available N is likely to be taken up by the growing plant.

Comparison with conventional mixed systems

Modelled data from the OFS, showed lower overall losses from comparable organic than conventional mixed systems (Figure 1). Similar results were obtained when nitrate losses from organic farming rotations were compared with conventional farms, on similar soil types, operating under the Nitrate Sensitive Area scheme (NSA) (Lord *et al.*, 1997). However, the data from the conventional farms, within NSAs, farming practices had been modified specifically to achieve a reduction in nitrate leaching.

There is a number of strategies that might be explored to further reduce nitrate leaching from mixed organic farming systems. For example, delaying the cultivation of the ley, avoiding grazing prior to ploughing out the ley, and the greater use of spring cropping and cover crops. Soil type clearly affects the total amounts of N available and the timing of leaching loss (Figure 2). It might be possible to produce soil type specific guidelines to reduce nitrate leaching losses. These could be achieved through adoption of good practice guidelines or through changes in organic standards.

Conclusion

Reducing N loss from food production systems is an important objective, however, some leaching loss is inevitable from an agricultural system due to the disturbance of the soil, and the import and export of nutrients is unavoidable. The measured leaching losses from mixed organic systems and conventional farms operating under NSA schemes are similar. Therefore, it can be concluded that organic farming could be an effective option for meeting the EU directive.

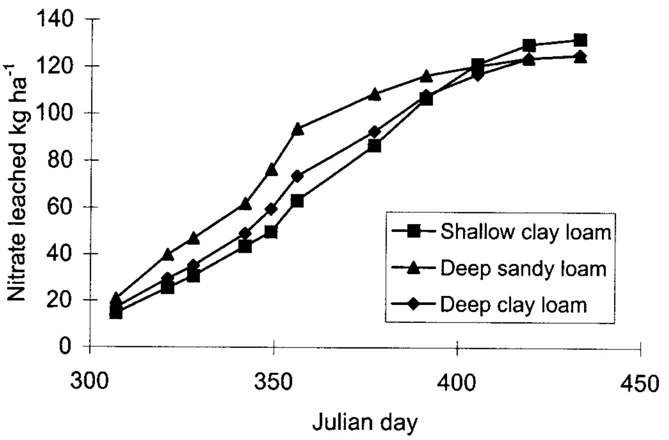

Figure 2. The rate of nitrate leaching losses according to soil type.

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THE ROLE OF GRASS-CLOVER LEYS IN MIXED FARMING SYSTEMS

Establishment of herbage legumes and grass-clover leys in mixed farming systems

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Introduction

Good and rapid establishment of grass-clover leys and herbage legume green manures is an essential pre-requisite for achieving high levels of output in mixed farming systems, particularly in low-external input systems that largely rely on biological N_2-fixation by legumes as the primary source of N input to the system. Satisfactory establishment (for example, in a ley: 6000 tillers m^{-2} of perennial ryegrass and 1000 growing points m^{-2} of white clover) is the primary objective, but practical considerations of how the establishment phase is integrated in the rotation must also be taken into account. It is important that the sown sward reaches its optimum productive capacity as soon as possible after sowing, that the length of time the land is out of production during the establishment phase is kept to a minimum, that the cost of the establishment procedure, i.e. cultivations and sowing, is minimized, and that any potential competitive impact of the establishing sward on the previous crop is minimized.

The north and east of Scotland is traditionally a mixed farming area with a typical rotation of three or four years grass-white clover ley, followed by a spring cereal, root crops and spring cereal undersown. This rotation has been abandoned to a greater or lesser extent since the end of the Second World War, following the widespread adoption of fertilizer and herbicide use. However, such rotations are the mainstay of organic and extensive systems of farming and there is an increasing trend towards such systems, for either commercial or environmental reasons.

The objective of the experimental programme described in this paper was to quantify the influence of the major factors affecting establishment of perennial ryegrass (PRG), white (WC) and red (RC) clover, in particular the effects of the presence or absence of spring cereal cover crops, seedbed nitrogen (N) fertilizer, sowing date, seedbed preparation and sowing method, and initial soil moisture content. The experiments, both in the field and in the glasshouse, were carried out at SAC Aberdeen over a period of 17 years. The influences of seed rate of herbage and cereal cover crop, and of row spacing of cover crops on clover establishment have also been examined but are not presented here.

Material and methods

Experiment 1: Effect of undersowing, N application and date of sowing on perennial ryegrass and white clover establishment

The effect of plant density of PRG and WC was measured over a period of 12 months, following sowing in April 1982, either with or without a spring barley cover crop in a replicated field plot experiment. Four N fertilizer rates (N_{60}, N_{80}, N_{100}, N_{130} kg ha^{-1}) were applied to undersown (US) and two N rates (N_0, N_{130} kg ha^{-1}) to direct sown (DS) treatments. A further treatment involved direct sowing, with 30 kg N ha^{-1}, in late August (AS_{N30}), after harvesting spring barley that had received 100 kg N ha^{-1} at sowing in April.

Experiment 2: Effect of seedbed preparation and sowing method on autumn sown perennial ryegrass-white clover establishment
Plant density of PRG and WC was measured over a period of eight months following direct sowing in August 1982 after winter barley, in a field scale comparison. Three seedbed preparation and sowing treatments were compared: ploughing, surface cultivation of stubble using a land-driven rotary cultivator, and direct drilling into uncultivated stubble.

Experiment 3: Effect of stubble burning and sowing date in autumn on perennial ryegrass establishment
Plant density of PRG was measured over a period of eight months, following direct drilling into uncultivated stubble in late summer 1983 after winter barley, in a field scale comparison. Two sowing dates were compared: mid-August and mid-September, combined with or without straw and stubble burning.

Experiment 4: Effect of soil moisture content and seed rate on establishment of white and red clover undersown with oats
Establishment (herbage biomass) was measured of red or white clover, undersown at 5 kg ha^{-1} or 15 kg ha^{-1} seed rate, with spring oats in pots maintained at three levels of soil moisture content in the glasshouse: 15% moisture content (mc) by weight, 20% mc, 25% mc.

Experiments 5 and 6: Effect of variety height of oat or barley cover crops on establishment of red clover
Establishment (herbage biomass) was measured of red clover undersown with three varieties each of oats or barley in two replicated field plot trials. Oat and barley varieties differed in terms of straw height and were classified as short, medium and long.

Results

Effect of undersowing or direct sowing (Experiments 1, 4, 5, 6)

Effect of cover crop and N application Results from Experiment 1 illustrate the significant adverse influence of undersowing and N application on establishment of white clover (Table 1), even one year after sowing. Direct sowing in spring, without fertilizer N, resulted in four times and 18 times more clover growing points m^{-2} than undersowing with barley applied with 80 and 130 kg N ha^{-1}, respectively. Applying 130 kg N ha^{-1} to a direct sown sward reduced clover density by 50% compared to the unfertilized direct sown control. In contrast, at the same stage, one year after sowing, tiller density of perennial ryegrass was similar in all treatments, although prior to harvest of the cover crop, ryegrass tiller density in

Table 1. Effect of undersowing, N application and date of sowing on perennial ryegrass and white clover establishment, one year after sowing.

Treatment		Ryegrass tiller density (no m^{-2})	Clover density (growing points m^{-2})
DS_{N0}	Direct sown April, no N	6326	1080
DS_{N130}	Direct sown April, 135 kg N ha^{-1}	6384	549
AS_{N30}	Direct sown Sept., 30 kg N ha^{-1}	6392	101
US_{N60}	Undersown April, 60 kg N ha^{-1}	6896	159
US_{N80}	Undersown April, 80 kg N ha^{-1}	6647	248
US_{N100}	Undersown April, 100 kg N ha^{-1}	7874	77
US_{N130}	Undersown April, 130 kg N ha^{-1}	6326	61

undersown treatments (circa 1000 tillers m^{-2}) was only 25 to 30% of that in spring direct sown treatments (circa 4000 tillers m^{-2}).

Effect of species and variety of cereal cover crop Red clover develops much more vigorously under spring barley than under spring oats (Table 2). In Experiments 5 and 6, on adjacent sites, cereal biomass, and in particular crop height, was much greater in oats than in barley (although tiller density was greater in barley) and this resulted in a red clover biomass in undersown oats that was less than a quarter of that in barley. In contrast, the effect of cereal variety straw height on clover development was relatively minor, although there was a noticeable trend for shorter varieties to encourage clover biomass.

Effect of soil moisture content Soil moisture content has a stronger influence on the undersown clover component than on the cereal component (Figure 1; Experiment 4). In this pot experiment, increasing soil moisture content from 15% to 25% resulted in an increase in oat biomass of only 10-20%, but in a 159% increase in biomass of the red clover component and a 232% increase in white clover biomass.

Effect of stubble burning and sowing date in autumn

Table 1 (Experiment 1) illustrates how direct sowing in spring leads to significantly better white clover establishment than direct sowing in autumn. In Experiment 3, delaying sowing

Table 2. Effect of variety height of oat or barley cover crops on biomass of undersown red clover.

	Spring barley		Spring oats	
Cereal straw length	Grain yield (t ha^{-1} @15%mc)	Clover biomass (kg DM ha^{-1})	Grain yield (t ha^{-1} @15%mc)	Clover biomass (kg DM ha^{-1})
Short	5.1	1.45	5.9	0.34
Medium	5.1	1.16	6.3	0.24
Long	5.7	1.27	6.2	0.22

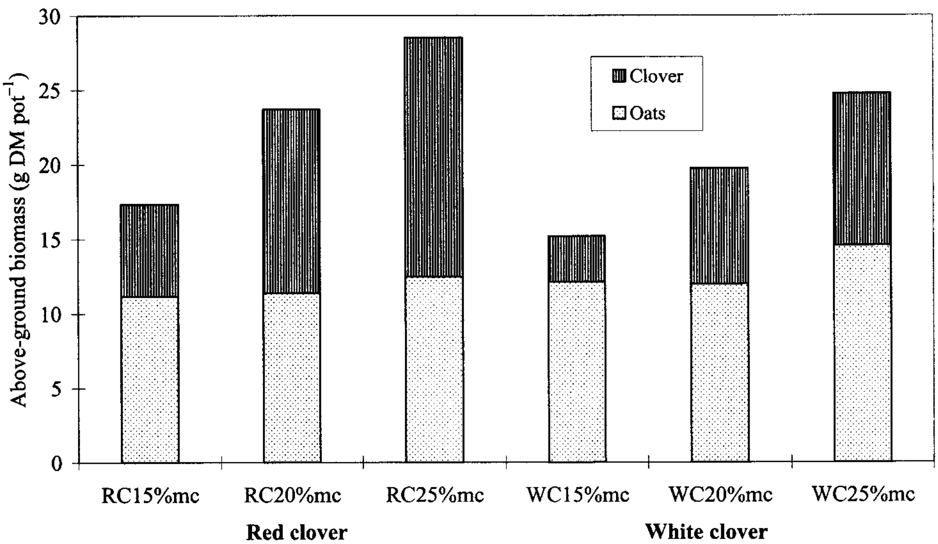

Figure 1. Effect of soil moisture content (mc) on above-ground biomass in oat-clover intercrops.

Table 3. Effect of stubble burning and sowing date in autumn on perennial ryegrass establishment in following spring.

Treatment: Date of sowing	Stubble burning	Ryegrass tillers (no m^{-2})	*Poa* plants (no m^{-2})	First cut silage yield (t DM ha^{-1})
18 August	No	4018	1201	5.02
18 August	Yes	4250	101	6.09
15 September	No	2881	756	4.88
15 September	Yes	3054	161	4.41

Table 4. Effect of seedbed preparation and sowing method in August sown perennial ryegrass-white clover establishment in the following spring.

Treatment	Ryegrass tiller density (no m^{-2})	First cut silage yield (t DM ha^{-1})
Ploughing	5998	4.4
Minimal cultivation	5037	4.2
Direct drilling	4896	4.0

by four weeks from mid-August to mid-September and without stubble burning resulted in a 28% lower tiller density of perennial ryegrass and a 16% lower silage yield in the first cut in the following spring (Table 3). The main effect of stubble burning in this situation was a substantial reduction in germination and establishment of *Poa annua*.

Effect of seedbed preparation in autumn sown grass

In Experiment 2, ploughing the cereal stubble prior to sowing in August gave a 16-18% increase in ryegrass tiller density in the following April, compared to minimal, surface cultivation and direct drilling (Table 4). Cultivation methods also showed very large differences in *Poa annua* and volunteer barley establishment. As ploughing effectively limited the germination of these weed seeds, the other cultivation treatments failed to do so, resulting in seven and ten times more seedlings m^{-2} of *Poa* and barley than in ploughed areas in October, two months after sowing.

Discussion

Within the context of achieving good and rapid establishment of the ley, sowing in spring without a cereal cover crop is the ideal approach. White clover in particular benefits from this strategy, especially without N fertilizer inputs. This is illustrated by farmers' experiences of establishing swards in spring during the set-aside period, which invariably results in spectacular clover establishment. However, outside the set-aside period, many farmers prefer to undersow rather than to direct sow in spring, because undersowing reduces cultivation costs and increases overall output per hectare in the establishment year. If an undersowing strategy is adopted, the data from Experiments 5 and 6 clearly indicate that spring barley should be used as the cover crop, rather than spring oats. Apart from the earlier maturity date of barley, that permits earlier removal of the cover crop, the oat canopy appears to intercept light to a larger degree than that of barley, resulting in a reduced level of light availability to the undersown species.

Direct sowing in spring is the ideal strategy in extensive or organic systems, the low use or absence of N fertilizer in undersown crops in these systems (and the generally lower crop yields) will at least restrict the adverse influence of N fertilizer and undersowing on clover establishment. The presence of a cereal cover crop also exacerbates the effect of soil moisture deficit – clover and grass establishment are strongly influenced by soil moisture availability, even without such competition, but sward establishment could be stimulated in the undersowing situation by harvesting the cereal crop for whole crop silage, thus lengthening the period during which the clover and grass can develop shoot and root systems, without the competitive presence of the cereal.

Establishment of white clover is much poorer after autumn sowing than after spring sowing. In contrast, good establishment of perennial ryegrass can be achieved following autumn sowing, but even with these rapidly establishing species, in our experiments there was a considerable penalty in tiller density and silage yield, by delaying sowing from mid-August until mid-September.

The value of inverting the soil by mouldboard ploughing was apparent in these trials.

Seedbed preparation using soil inversion has two principal advantages in organic and low-input systems: firstly it buries weed seeds that might have accumulated on the soil surface during the previous crop, and secondly, it aerates the soil and improves the availability of N for the establishing sward through mineralization of soil organic N. The advantage of stubble burning in terms of reduced weed invasion was apparent in these trials, but ploughing can achieve comparable results without the loss of organic matter and environmental hazards associated with burning.

These results show that the establishment of grass and especially clover on mixed farms is strongly influenced by a number of agronomic factors related to the interaction between arable and grass phases of the rotation. Many of these factors are under the control of the farmer. Within the climatic constraints of the farm it is possible, therefore, to adopt an establishment strategy maximizing the rate at which a dense, clover-rich sward can be established on a regular and reliable basis and so ensure maximum herbage production and livestock output.

The use of clover in grassland as part of a mixed farming system

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Introduction

Soils that are not or less suitable for cultivation are mostly used as permanent grassland. Permanent grasslands can also be found on soils that would allow cultivation (e.g., in some regions of The Netherlands), if this is economically attractive or for historical reasons. Grassland can be either grazed, cut, or both. Leys are grasslands that exist only a few years and are then ploughed-up as part of arable crop rotations. Leys can maintain soil fertility by adding and conserving N and organic matter. Mixed farms have a crop and a livestock component.

In the past, many farms have been specialized to livestock farming or, on suitable soils, to arable cropping, but ley farming is commonly practiced in organic farming systems. Peel & Lloveras (1994) put forward arguments against a substantial increase in ley-arable farming: it is not always economically attractive and physical and climatic factors often do not favour mixed farming. Nevertheless, currently there is increased interest in designing more integrated sustainable farming systems, because mixed farming may help to reduce emissions of N to the wider environment (Watson & Atkinson, 1995; Scholefield & Smith, 1996; Lantinga & Rabbinge, 1997).

In grass-legume mixtures, biologically fixed N can replace fertilizer N which saves fossil energy. Clover can, therefore, decrease the dependency on external inputs in grassland. In mixtures, the amount and timing of N input are more difficult to regulate than in grassland with only grasses, which is a disadvantage from an environmental viewpoint. In the current regulations for nutrient budgets in The Netherlands (MINAS, Mineral Accounting System), biologically fixed N is not included, because it is very difficult to estimate the amount of N fixed in practice.

In mixed swards, clover persistence is often poor, although the proportion of clover can fluctuate strongly (Elgersma & Schlepers, 1997). Various crop and soil parameters were measured in two cutting trials, on a clay and a sandy soil, with monocultures and mixtures of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) to study N and organic matter flows.

Material and methods

In April 1991, the first trial was established on former arable land on heavy river clay at Wageningen, The Netherlands. Perennial ryegrass was sown in monocultures and in mixtures with white clover. The plots were fertilized with P and K only. The trial was cut at dry matter yields of about 1200 or 2000 kg ha^{-1} (5-8 cuts annually) from 1991-1997.

Table 1. Results of grass-clover mixtures without fertilizer-N under cutting, sown April 1991 on clay soil (Source: Elgersma & Schlepers, 1997; Elgersma *et al.*, 1998).

Year	1992	1993	1994	1995	1996
DM yield (t ha^{-1})	12.2	10.5	8.7	11.7	8.5
Clover DM yield (t ha^{-1})	8.7	6.5	4.1	7.1	4.2
Clover content (% of DM)	71	61	46	60	48
N yield (kg N ha^{-1})	507	406	265	420	263
Apparent N_2-fixation (kg N ha^{-1})	470	380	238	393	236
N transfer to grass (kg N ha^{-1})	69	92	69	90	72
Clover-derived N (kg N t^{-1} clover DM)	54	60	59	55	60

The apparent N_2-fixation by clover was calculated by the difference method: by subtracting the N yield of the grass monocultures from the total N yield of the mixtures. The apparent N transfer was estimated as the difference between grass N yield of the mixtures and that of grass monocultures. Various plots were sampled during three winters (1992-93, 1994-95 and 1996-97) to measure NO_3^- losses with two ceramic cups per plot at 60 cm below the soil surface (Elgersma *et al.*, 1996).

The second trial was sown in autumn 1995 on sandy soil with mixtures and grass and clover monocultures (Nassiri, 1998). In 1997, mixtures were fertilized with 0 or 180 kg N ha^{-1} and grass plots with 0, 180 or 360 kg N ha^{-1}. Nitrate concentrations were determined as described above, from November 1996 onward.

Results

In both trials, yields of the unfertilized grass monocultures were far less than those of the mixtures. The mixtures with large-leaved clover cv. Alice yielded most during the whole season in all harvest years. There was no significant effect of grass cultivar on total herbage production.

Mean annual yield values of the trial on clay soil are summarized in Table 1. There was a positive, significant overall relationship between clover content and total herbage yield. However, this was due mainly to the effect of year (1992 > 1993, 1995 > 1994 and 1996) and clover cultivar (Alice > Gwenda > Retor): within years there was no effect of clover content on total herbage yield within each mixture (not shown). Apparent N_2-fixation was very high, ranging from 150 to 545 kg N ha^{-1} in the different mixtures.

Net N mineralization rate was lower under monocultures than under mixtures on clay soil (Figure 1), and in three out of four sampling even negative. C mineralization and the amounts of C and N in active soil organic matter fractions were similar for monocultures and mixtures, but the C:N ratio of the active soil organic matter fractions was higher under grass than under mixtures. This explains the lower N mineralization under grass (Elgersma & Hassink, 1997).

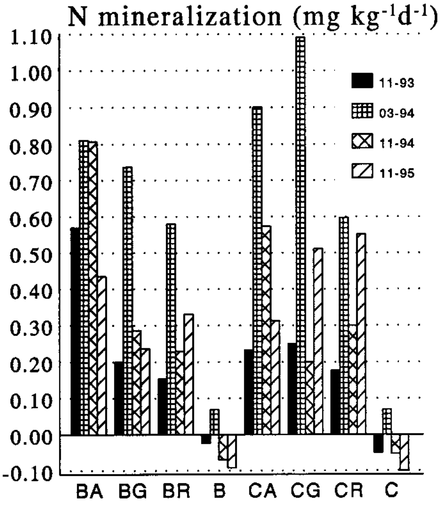

Figure 1. Potential N mineralization in the top 10 cm soil layer (mg N kg^{-1} soil d^{-1}) under six grass-clover mixtures (BA, BG, BR, CA, CG, CR) and two grass monocultures (B, C) during 4 sampling dates. From: Elgersma & Hassink, 1997.

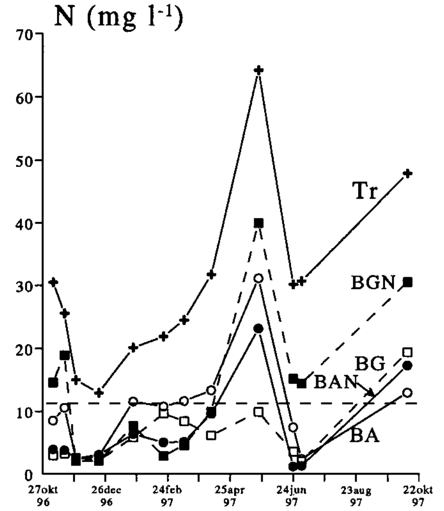

Figure 2. Nitrate concentrations (mg l^{-1}) at 60 cm depth under pure clover (Tr) and mixtures with grass cv. Barlet and clover cv. Alice (BA) or Gwenda (BG), without and with (BAN, BGN) N fertilizer.

Even under plots with a very high (> 75 %) clover content, the EU-limit (11.3 mg N l^{-1} in NO_3^-) was not exceeded on clay soil (Elgersma & Schlepers, 1997). Nitrate losses from the unfertilized grass monoculture were significantly lower than from grass-clover mixtures: the amount of N lost during winter was less than 1 kg ha^{-1}. Significant differences were found among mixtures for the amount of N lost by leaching, plots with the large-leaved clover cv. Alice showing the highest losses (up to 10 kg N ha^{-1} per winter). On clay soil, however, N is less likely to leach but may be lost by e.g. denitrification or be immobilized.

In the experiment with cut swards with the same mixtures on sandy soil, nitrate leaching losses were much higher than on clay. They exceeded the EU-limit at several sampling dates throughout the year, especially the unfertilized Barlet/Alice mixture and the fertilized Barlet/Gwenda mixture, whereas pure clover swards exceeded the limit at all sampling dates (Figure 2). Below grass fertilized with 180 kg N (not shown) negligible nitrate concentrations were found (< 3 mg N l^{-1}), whereas under grass fertilized with 360 kg N they ranged from 2 to 4 mg N l^{-1} up to April and were thus similar to those under mixtures. In May, when all mixtures except unfertilized Barlet/Gwenda had nitrate concentrations that highly exceeded the limit (Figure 2), 11.5 mg N l^{-1} was measured under grass with 360 kg N. In June and July, 8.4 and 5.1 mg N l^{-1}, respectively, was measured, and in October 1997, 32 mg N l^{-1} after an N application of 80 kg N on September 17.

Discussion

Grassland production faces increasing costs due to stringent environmental protection measures, e.g. for modifications of slurry storage and application. The main overall research problem for production grasslands in The Netherlands is to find management options which meet the requirements for profitable farming and comply with the prevailing environmental demands. Mixed farms may be better suited to meet these demands.

It is generally assumed that legumes are an essential part of sustainable farming systems, because of their potential to fix N. However, this may be questioned. Sprent & 't Mannetje (1996) and Chapman *et al.* (1996) put forward some critical points and future prospects. If legumes are to be used efficiently in sustainable grassland or mixed farming systems, their N fixing potential must be optimized, which needs a better understanding of how legumes function.

Higher concentrations of nitrate were measured under pure clover swards and pure grass swards fertilized with 420 kg N ha^{-1} (both high-N input swards) than under low-N input unfertilized grass and grass-clover swards (Macduff *et al.*, 1990). We (Figure 2) also found the highest losses under pure clover, but grass fertilized with 360 kg N ha^{-1} had similar or lower losses than the mixtures (except for one sampling date in autumn after a very high late N application). Grass fertilized with 180 kg N ha^{-1} always had lower losses than grass-clover mixtures.

A high clover content in swards is likely to increase losses of N to the environment. As the biologically fixed N has entered the clover plants in the grassland-animal system, it behaves in a similar way as N from other sources and is equally subject to losses ('t Mannetje & Jarvis, 1990). Leaching losses from cutting systems are much smaller than from grazed pastures, where scattered dung and particularly urine patches with high N concentrations form major sources of N losses to the environment, even in unfertilized grass-clover pastures (Elgersma *et al.*, 1996).

Scholefield & Smith (1996) stated that while the organic farming movement stimulates the current interest in re-evaluating ley-arable systems, the gain in efficiency of N-use may be higher and the transition to mixed farming may be more attractive economically at higher levels of inputs. However, this seems debatable as at higher levels of N circulating in a system, losses will also increase. Moreover, as N_2-fixation declines at higher soil N availability, the highest benefits from legumes are obtained at low input systems.

Høgh-Jensen (1996) studied the effect of clover-based versus ryegrass-only swards (both unfertilized and cut during two years) on the succeeding cereal crop in a ley system. The amount of N derived from clover-ryegrass residues was 25 to 43% higher than that from ryegrass. Because of the higher predicted input of organic N in residues of stubbles and roots, predicted net N mineralization after grass-clover (140 kg N ha^{-1}) was higher than after grass (63 kg N ha^{-1}). Five times more inorganic N was leached after grass-clover than after grass (54 versus 11 kg ha^{-1}). In ley systems, potential leaching losses (occurring after ploughing) are much higher than in permanent pastures.

Conclusions

Mixed farming systems often include a grassland component. The dependence on external inputs in grassland can be reduced by clover, because biologically fixed N can replace fertilizer N. However, the amount and timing of N availability are more difficult to regulate in grass-legume swards than in fertilized grasslands, which is an environmental constraint. During the grassland phase, nitrate losses below mixtures on a clay soil were low, but on a sandy soil they exceeded the EU limit and were higher than under grass fertilized with 180 kg N ha^{-1} and similar or higher than under grass fertilized with 360 kg N ha^{-1}. Moreover, from literature it appears that in ley systems with clover, large leaching losses may occur after ploughing.

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Biological nitrogen fixation in grass-clover leys and its transfer to subsequent crops

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Introduction

Mixtures of white clover and ryegrass are dominating low-N-input temperate pastures. In these pastures, both the clover content and the biological N_2-fixation (BNF) can vary considerably and are difficult to control by management. A large part of the variation in annual BNF is related to differences in the white clover content of the herbage (Kristensen *et al.*, 1995). The competitive balance between clover and ryegrass depends on the eco-physiological characteristics of the plants and may change with year-to-year differences in weather or management. Under most conditions, competition for water and inorganic N seems to predominate and the N_2-fixation rate will, under field conditions, depend on the availability of these two factors (Crush, 1987; Harris, 1987).

The advantages of mixing non-legumes and legumes in different types of intercropping systems are most frequently evaluated relative to pure stands. Transfer of atmospherically derived N from clover to ryegrass or application of fertilizer N may stimulate the ryegrass in the mixture. This may change the balance between clover and ryegrass and, therefore, affect the N_2-fixing activity and the utilization of soil N and water.

Interactions between white clover and ryegrass under contrasting N availability have been investigated in field experiments over three consecutive years with respect to N_2-fixation, N fertilizer recovery, N transfer from clover to grass, and water use efficiency, as partly reported in Høgh-Jensen & Schjoerring (1997a). In addition, the transfer of atmospherically derived N from grass-clover leys to subsequent cereal crops has been determined by ^{15}N labelling and mathematical modelling as partly reported in Høgh-Jensen & Schjoerring (1997b).

Material and methods

In a three-year field experiment four replicate plots (sandy loam, at 10-20 cm depth: 5.3% clay and 10.2% silt) were established with white clover in pure stand, perennial ryegrass in pure stand or mixtures of white clover and ryegrass in seed ratios of 1:20, 6:20 or 12:20 white clover:ryegrass seed (kg ha^{-1}). To simulate urine deposition in pastures, urea was applied to these mixtures in amounts of 3, 24, 48, or 72 kg N ha^{-1} yr^{-1}. No irrigation took place. In all cases ^{15}N methodology was employed (for details: Høgh-Jensen & Schjoerring (1997a). A mathematical model called DAISY (Hansen *et al.*, 1991) was used for simulating the N turnover after incorporating the sod (Høgh-Jensen & Schjoerring, 1997b).

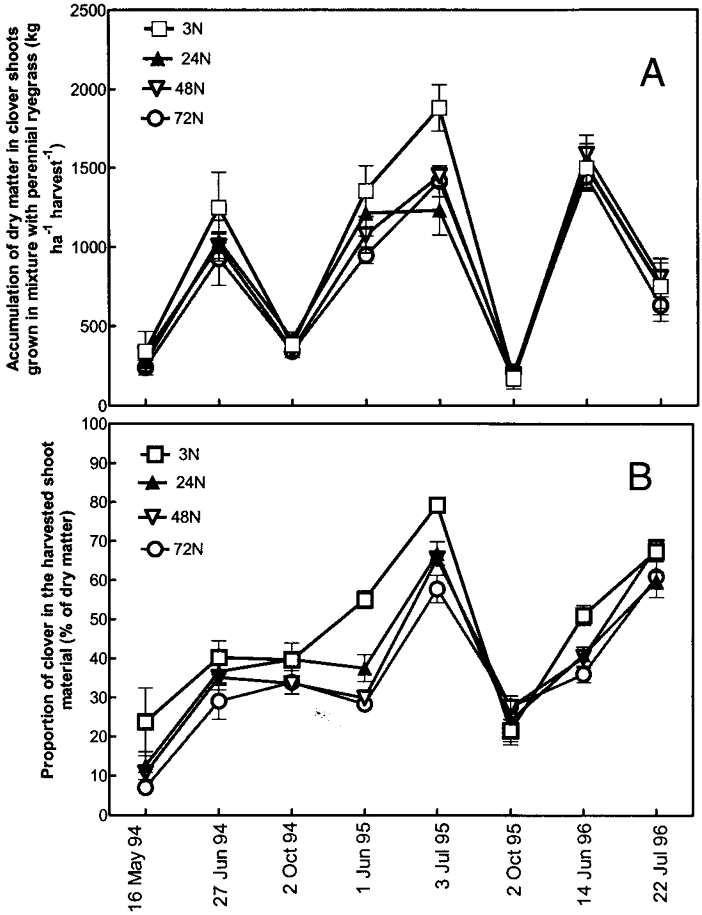

Figure 1. Amount of (A) white clover dry matter accumulated at each harvest and (B) white clover content of shoot material harvested in ryegrass-clover mixtures (seeding ratio 6:20; kg clover seeds:kg ryegrass seeds) growing at four levels of fertilizer N application (kg N ha^{-1}).Vertical bars indicate standard errors.

Results and discussion

Biological N_2-Fixation (BNF) in harvested clover shoots

Averaged over the N treatments the accumulation of dry matter (DM) in the harvested grass-clover shoots was 6.5, 6.1 and 4.8 t DM ha^{-1} for the first, second and third production year, respectively. Hence DM accumulation was only 55% of that in similar experiments under fully irrigated conditions (Vinther & Aaes, 1996).

The total amount of atmospherically derived N in clover, growing in mixture with ryegrass was, on average over the three years, equal to 83, 71, 68, and 60 kg N ha^{-1} for the treatments of 3, 24, 48, and 72 kg N ha^{-1}, respectively. The proportion of atmospherically derived N declined with increasing N application, but never became smaller than 80% of total clover N. Thus, N_2-fixation constituted a high proportion of the total N accumulated by the clover during water-limited growth conditions.

Clover content in relation to seeding ratio and N application

Clover dry matter accumulation in the shoots varied with time in the growing season, but the clover content of the harvested shoot material (%clover on DM basis) varied disproportionally during the three production years (Figure 1). The 3N treatment tended to have the highest %clover whereas the effect of the other N treatments did not differ (P>0.05).

The seeding ratio had a strong effect on %clover in the first production year. However, this effect interacted with N treatment so that seed ratio of 1:20 under a low N regime only reached the same high %clover (≈35%) as the seeding ratio of 6:20 and 12:20 after the first production year. Where a small white clover population was established (1:20) at high rates of N application, one growing season was not sufficient to achieve a similar %clover as in

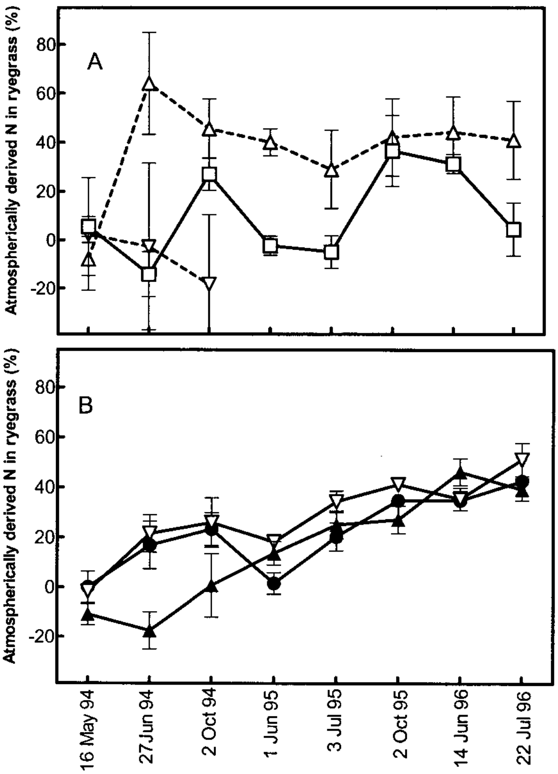

Figure 2. Proportion of atmospherically derived N in shoot material of ryegrass growing in mixture with white clover under (A) three different seeding ratios (∇) 1:20, (□) 6:20, (Δ) 12:20) with fertilizer N application of 3 kg N ha^{-1} yr^{-1} or (B) three different fertilizer N applications (▲) 24 kg N ha^{-1}, (∇) 48 kg N ha^{-1}, (●) 72 kg N ha^{-1} with the seeding ratio of 6:20 kg clover seeds:kg ryegrass seeds. Vertical bars indicate standard errors.

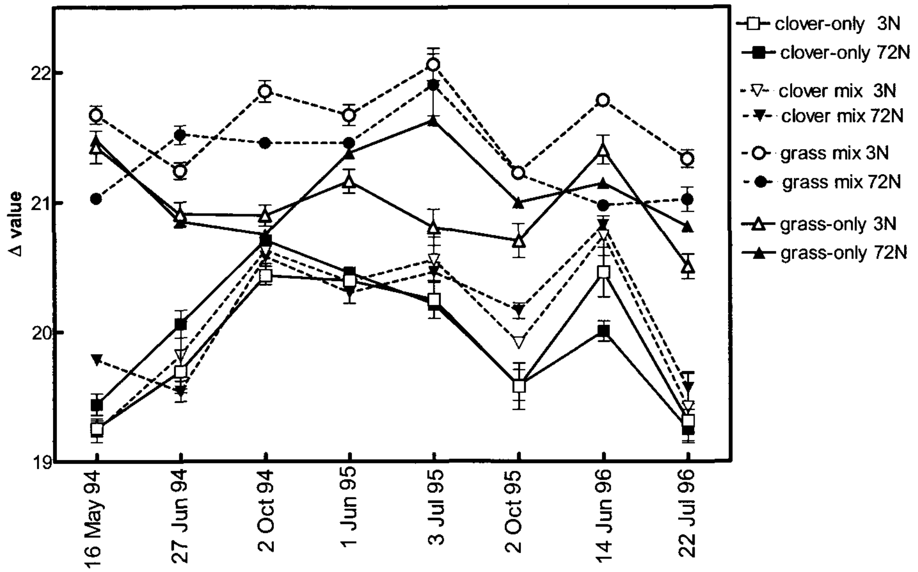

Figure 3. Carbon isotope depletion relative to atmospheric ^{13}C content (‰) in shoot dry matter of (□, ■) pure stand white clover, (Δ,▲) pure stand ryegrass, (∇,▼) white clover in mixture, or (O, ●) ryegrass in mixture. Carbon isotope discrimination is negatively correlated with water use efficiency (Farquhar & Richards, 1984; Høgh-Jensen & Schjoerring, 1997c). Data are means SE (n=8) of treatments receiving 3 and 72 kg N ha^{-1} for the seeding ratio 6:20 (kg clover seeds:kg ryegrass seeds).

the higher clover:ryegrass seeding rates. Consequently, at the low seeding ratio, white clover DM and N yields in the 48N and 72N treatments were significantly lower than those in the lower N treatments ($P<0.05$). No significant differences in %clover were observed in the 3N and 24N treatment at the end of the first production year. Accumulation of both DM and N in ryegrass was not affected by the initial clover population.

BNF in harvested grass shoots

The average amount of atmospherically derived N transferred to the associated ryegrass was 4, 12, and 16 kg N ha^{-1} in the first, second, and third production year, respectively. Expressed relative to the total amount of fixed-N_2 in the ryegrass-clover mixture, the transfer amounted to 3, 17, and 22% in the first, second, and third production year, respectively. Thus, transfer of atmospherically derived N from clover contributed significantly to the N economy of the associated ryegrass. This contribution was stimulated by a high clover density (Figure 2) and moderate application of fertilizer N.

Competition for inorganic nitrogen and soil water

The ryegrass-clover mixture absorbed consistently higher amounts of soil-derived N than the pure stands of the two species (Table 1). Only 11% of the total accumulated fertilizer and soil-derived N in the mixture was contained in the clover component. Lower water use efficiencies for the plants grown in mixture, compared to pure stands, were related to the increased N uptake in the mixture, with the subsequent increase in growth compared to the pure stands (Figure 3). The positive interactions between clover and ryegrass growing in mixture thus ensured more efficient fixation of atmospheric N_2 and absorption of fertilizer N and soil derived N than pure stands of the same species.

Residual nitrogen effect

After ploughing-up the ley, the amount of N, in a subsequent wheat crop, derived from ryegrass-clover residues was 25 to 43% higher than that derived from residues of pure stand ryegrass. Expressed in absolute values, N uptake in the subsequent winter wheat crop was 5-10 kg ha^{-1} higher after ryegrass in pure stand, but 23-28 kg ha^{-1} higher after ryegrass-clover in mixture. This difference must be attributed to atmospherically derived nitrogen.

Up to about 54 kg ha^{-1} of the N mineralized from the ryegrass-clover crop was leached, whereas only 11 kg ha^{-1} was leached following grass in monoculture.

Table 1. Above-ground contents of soil-derived nitrogen for white clover in pure stand, ryegrass in pure stand, and white clover and ryegrass in mixture under application of different amounts of urea.

Crop component	N treatment (kg N ha^{-1})	1994	1995	1996
			(kg N ha^{-1})	
Clover	3	27	38	20
in	24	33	31	17
pure stand	48	29	22	26
	72	38	34	25
Clover	3	3	7	5
in	24	5	6	8
mixture	48	5	3	8
	72	4	6	9
Ryegrass	3	48	48	24
in	24	68	48	27
mixture	48	72	42	24
	72	93	49	26
Ryegrass	3	41	23	13
in	24	57	27	23
pure stand	48	70	27	18
	72	75	35	26
F-test	Crop	***	***	***
	N treatment	***	ns	ns

When simulating a delay in ploughing-in of the residues, the poorer crop development before winter was counteracted by the higher absorption of inorganic N in the subsequent spring because N leaching was reduced to 30 kg ha^{-1}. When further delaying ploughing to spring, N absorption was simulated to be even higher than in an autumn-sown cereal crops and N leaching was reduced to 16 kg N ha^{-1}.

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Management and output of grass-clover swards in mixed farming systems

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Introduction

The increased input of nitrogen (N) has made an important contribution to the improvement of grassland productivity since World War II, especially in the Netherlands where fertilizer N is extensively used on grassland. For 70% of the Dutch grassland area, recommended annual rates are about 400 kg N ha^{-1} at present (Anonymous, 1997). However, in Dutch dairy farming with predominantly grazing, only 16% of the total N input in fertilizer and purchased feeds is converted in milk and meat and the dairy sector is responsible for 55% of the N surplus in agriculture (Van Keulen *et al.*, 1996). According to Van Bruchem *et al.* (1996), the most pronounced reduction in N losses occurs when inputs of fertilizer N are restricted. Lantinga & Groot (1996) showed that minimal N losses per unit product are achieved from grassland fertilized with *ca* 200 kg N ha^{-1} yr^{-1} under integrated grazing and mowing management leading to a reduction in grassland productivity of only 10%. In such a situation, the apparent recovery of N in grass from fertilizers and manure approximates 80% whereas N input per ha is halved. This is a big improvement compared with current practice where the apparent recovery is around 40% (Van Bruchem *et al.*, 1996). Such findings are the result of new research programs in North-western Europe where a move has taken place from increasing the quantity of production based on excessive amounts of N fertilizers to a search for alternative methods less dependent on this resource. This has led to a renewed interest in grass-clover associations as a basis for low input, but highly productive grassland-based dairy systems and mixed farming systems.

The use of legumes in mixed farming systems

In ecological agriculture, legumes are indispensable for the necessary input of N at the farm level. Mixed farming systems of dairy and arable enterprises, which have nearly disappeared in Dutch agriculture due to specialization during the last decades, undergo a renaissance (Lantinga & Rabbinge, 1997). This is due not only to the expansion of ecological agriculture where the production of arable crops relies mainly on animal manure and mineralization, but also to a growing belief that an intensive integration of the two sectors is one of the most promising ways to sustainable agriculture (Goewie *et al.*, 1998). In mixed farming systems, at farm or regional levels, the use of external inputs like fertilizers can be reduced to a great extend and their efficiency is improved due to several factors. One of them is the inclusion of grass monocultures or grass-legume mixtures in the crop rotation. This prevents the accumulation of organic N, typically for permanent grassland. After turning arable land to grassland, accumulation of soil N can be as high as 190 kg N ha^{-1} yr^{-1} under grazing management (Hatch *et al.*, 1991; Cuttle & Bourne, 1992). One might consider this accumulation of soil N as a positive aspect, since in the long term net N mineralization rates will increase. However, when very old grassland is ploughed, soil organic N may decrease during the first five years with about 2000 kg N ha^{-1} causing substantial nitrate leaching losses (Whitmore *et al.*, 1992).

In ecological agriculture, leys consist of grass-legume mixtures with white and red clover and lucerne as the most common legume species. It is well-established that perennial ryegrass is the most compatible species in association with white clover, but for reasons of diversity other grass species are also included in mixtures used on ecological farms. White clover is the only temperate forage legume species which can persist under both frequent cutting and intensive grazing. In addition, its great ability for biological N_2-fixation and its high nutritive value give it an important role in low input grazing systems. According to Elgersma & Schlepers (1997), the N fixing capacity of new cultivars of white clover with improved cold tolerance and persistence may even exceed 400 kg N ha^{-1} yr^{-1} with clover dry matter yields up to about 10 t DM ha^{-1} in mixtures with perennial ryegrass. Red clover and lucerne are not persistent under grazing and in earlier days they were commonly grown as monocultures which were infrequently harvested by cutting. The production potential (excluding field losses) of the above described mixtures used on ecological farms is in the order of 14 t DM ha^{-1} yr^{-1} with 4-5 harvests per year. Recent experiences (Lantinga, unpublished) have revealed, however, that the feeding quality of these silages is below expectation and not sufficient to use them as the sole roughage for highly productive dairy cows during the winter period. The main weak point is the low digestibility caused by the necessary long regrowth periods in order to maintain lucerne in the mixture and the use of grasses other than perennial ryegrass. In this paper, results are presented from an integrated mixed farm where legumes are also used extensively in short-term grasslands but with a different botanical composition and management strategy. Net grassland output realized in 1997 is compared with results obtained in an experiment on the same farm in 1978-1980 when grass monocultures were used and only fertilizer N was applied.

Material and methods

On the Ir. A.P. Minderhoudhoeve in Oostelijk Flevoland (experimental farm of Wageningen Agricultural University) situated in an area reclaimed from the sea in the 1960s, an integrated prototype mixed farm is designed with limited use of fertilizer and biocides. The soil is a young sedimentary calcerous silty loam with 75% clay+silt. On this farm, the livestock component includes dairy cattle and sheep. The integrated farm aims at maintaining the recent high level of production with minimization of the nutrient losses per unit of product (Lantinga & Rabbinge, 1997). The basal feed component includes grass-clover leys for pasture and silage, maize silage and whole-wheat silage. During the winter season, the basal dairy feed consisted of (on dry matter basis) 37% grass-clover silage, 30% maize/wheat silage, 15% beet pulp and 18% wheat/barley straw. For young stock of 1-2 yr and dry cattle the mixed feed is composed of equal amounts of grass-clover, maize/wheat silage and wheat/barley straw dry matter. The maize/wheat silages are used for compensation of the N excess in the grass-clover mixture. The aim of adding straw is to improve the quality of the slurry, by increasing the C/N (energy/N) ratio. This approach is thought to influence the type of microbial fermentation in the hind gut and the slurry, which supposedly will reduce ammonia emission from the cow-shed, stimulate the microbiological activity in the soil and increase organic matter content in the soil, on the longer run leading to a more efficient nutrient management.

Separate grass-clover leys for grazing and mowing are placed in the rotation after seed potatoes and sown in late summer. After harvesting the potatoes, the following soil cultivation activities take place: (*i*) subsoiling with a dual tined subsoiler, (*ii*) soil loosening with a rigid tined cultivator, and (*iii*) seedbed preparation with a rotary harrow. Subsequently, the mixture is sown with a pneumatic precision fertilizer spreader, the seeds are incorporated in the topsoil with a weed harrow and finally the surface is rolled with a Cambridge roller. All this equipment is generally available on an arable farm and no contract-work is needed. Seed mixtures used until now are 25 kg tetraploid perennial ryegrass cvs. Elgon and Montagne and 5 kg white clover cv. Alice (grazing field) or 3 kg white clover cv. Alice and 2 kg red clover cv. Barfiola (mowing field). The duration of the ley for grazing is four years and that for mowing two years. Tetraploid cultivars of perennial ryegrass are preferred because of their proven good co-existence with white clover and their higher nutritive value and intake rates compared to diploid cultivars (Lantinga & Groot, 1996). The medium-leaved white clover cultivar Alice is selected since it shows both a high level of plasticity under different management strategies and high persistence under Dutch conditions (Elgersma & Schlepers, 1997; Lantinga, unpublished).

For the dairy herd of about 80 cows, 14 ha of pasture is available for day-time grazing. Maize or whole-crop wheat silage, (dried) beet pulp produced from the own farm, straw and concentrates are fed indoors during the night. Continuous grazing is applied, since this system is easy to handle, the cows are calm, the intake pattern is very regular, weeds are suppressed and the ratio between perennial ryegrass and white clover can be best controlled. The target is 40-50% clover dry matter (DM) in the sward during late summer and autumn. During periods of excess herbage growth, part of the pasture is fenced-off and cut for silage. In the mowing ley of 11 ha, four cuts are taken each year at a yield level of about 3000 kg DM ha^{-1}. The mown herbage is harvested as silage or hay, or artificially dried to produce pellets. In both treatments, no artificial fertilizers are applied and slurry is applied using shallow-injection equipment at annual rates of 60 (grazing paddock) or 90 m^3 ha^{-1} (mowing paddock). Due to the feeding strategy, the N content of the applied slurry in 1997 was only about 2.5 kg ton^{-1}, of which about 60% in inorganic form.

Table 1. Grazing system (rotational, continuous), fertilization, herbage intake, mown yields and net grassland output. One kVEM corresponds with 6.9 MJ Net Energy for Lactation and equals on average about 1.1 kg DM. FPCM is fat- and protein-corrected milk (4.0% fat and 3.4% protein).

	Grass monocultures (average 1978-80) day- and night-grazing		Grass-clover mixtures (1997) day-grazing
	Rotational	Continuous	Continuous
Kg fertilizer N ha^{-1} yr^{-1}	440	440	0
Kg slurry N ha^{-1} yr^{-1}	0	0	180
Intake from grazing (kVEM ha^{-1} yr^{-1})	7059	6991	3311
Silage, hay and pellets (kVEM ha^{-1} yr^{-1})	2082	2180	5914
Net grassland output (kVEM ha^{-1} yr^{-1})	9141	9171	9225

Results and discussion

Grassland output and nitrogen fixation

The main results are summarized in Table 1 and compared with earlier results from a 3-years' experiment on the same farm where rotational and continuous grazing systems were tested (Schlepers & Lantinga, 1985). In that experiment, the grassland area for each grazing system was about 13 ha (permanent grassland dominated by diploid perennial ryegrass) and fertilizer N was applied according to the recommendations at that time. For the present experiment, results obtained in 1997 from a first year's pasture and a second year's ley were pooled. Net grassland output was not different between the three systems (Table 1). Estimated average level of N_2-fixation in 1997 was about 260 kg ha^{-1} yr^{-1}, based on a mean clover content of 40% in the harvested dry matter, a total net yield of 11 t DM ha^{-1} and assuming 60 kg of biologically fixed N per ton of harvested clover DM (derived from Watson & Goss, 1997; Elgersma, 1998).

Sward height and botanical composition in the pasture

The grazing season started at the end of May after taking a silage cut. During June and July the mean sward height fluctuated between 8 and 13 cm, whereas around half July part of the grazed area was topped once to remove the reproductive grass stems and another part was fenced-off for taking a second silage cut. Between mid-August and early November the mean sward height decreased gradually from 9 to 5 cm. During the winter period the pasture was stocked with sheep for a couple of weeks and a visual inspection in spring 1998 revealed that the sward was in perfect condition with a balanced composition of grass and clover and virtually no weeds. During the grazing season the share of white clover in the herbage DM on offer, i.e. above about 2 cm sward height, increased from less than 20% to around 50% (Figure 1). This increase was reflected in the urea content of the milk which raised from about 25 mg $(100 ml)^{-1}$ in June to about 35 mg $(100 ml)^{-1}$ in October.

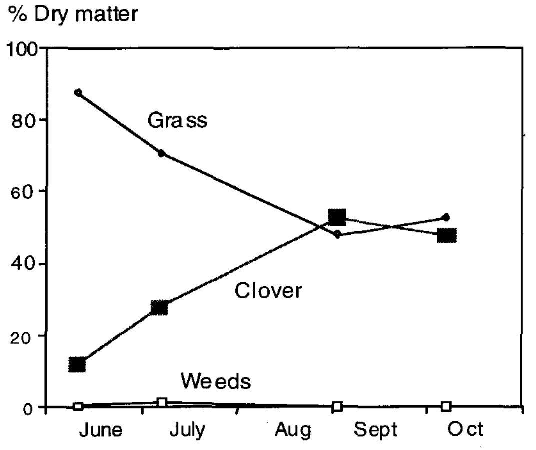

Figure 1. Botanical composition of the herbage on offer in the continuously-grazed pasture.

Soil mineral nitrogen

The amount of soil mineral N was measured in both fields at the start of the growing season (March) and in November. In all cases, the quantities up to a soil depth of 90 cm were below 100 kg ha^{-1} (Table 2). Autumn values were lower than those in spring, especially in the pasture, indicating that a great deal of the slurry N had been absorbed by perennial ryegrass. This minimizes the risk of significant leaching losses from the two grass-clover swards.

Conclusion

The presented results clearly demonstrate that, under proper management, short-term swards consisting of tetraploid perennial ryegrass, white and red clover and receiving only slurry can be just as productive as permanent monocultures of heavily fertilized diploid perennial ryegrass. As shown by British research in the 1980s, continuous grazing is an excellent grazing system to keep the clover content in the sward at the target level of 40-50% and to minimize grazing losses. The adopted management strategy with only one large grazing block (14 ha) and one large mowing block (11 ha) appears to be very successful in terms of

Table 2. Soil mineral N (kg ha^{-1}) in spring and autumn 1997.

	Spring				Autumn			
Soil layer	0-30 (cm)	30-60 (cm)	60-90 (cm)	Total	0-30 (cm)	30-60 (cm)	60-90 (cm)	Total
Mown paddock	47	37	13	97	62	10	6	78
Grazed paddock	36	24	23	83	24	3	3	30

easiness of handling operations, level of grassland output and botanical composition. The soil mineral N contents in autumn 1997 indicate that the risk of significant leaching losses was minimal, especially in the grazed area where less slurry was applied.

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MODELS FOR MIXED FARMING SYSTEMS

Using the static whole farm model FARM and the dynamic model NDICEA to integrate arable and animal production

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Introduction

Many ecological arable farms import manure from conventional farms and in The Netherlands a nearly unlimited stock of manure is available. In the near future this input will be more restricted, as ecological farms will be forced by their own organizations to rely on manure produced on ecological farms. Manure will then become a product of limited availability and farmers have to establish nutrient flows within networks of their farms in such a way that all farms can maintain a sufficiently high production level. Always, part of the nutrients will be lost from such networks (about 30%), through leaching and volatilization. The limited amount of urban waste compost (about 1 ton per ha arable land; Hertog, pers. comm.) and atmospheric deposition can compensate only a small part of this loss and further shortages will have to be balanced by inputs from outside the network based on nitrogen fixation and weathering of minerals. These networks will face the same problems as mixed ecological farms. On mixed ecological farms that do not import manure from outside, production levels and economic return are related to system-specific nutrient dynamics, governed by weather, soil properties, crop rotation, stocking rate, animal feeding, manure handling and manure allocation. A satisfactory combination of farms can iteratively be found by combining theoretical knowledge and local experience. Simple calculations on static relations can be combined with a dynamic approach to check whether the proposed network can supply enough N to attain intended yields without causing pollution of environment. Such a theoretical approach may help to avoid learning by bitter experience. In this paper such an approach will be demonstrated and evaluated by re-designing a current arable farm into a mixed farm. The aim is to replace import of manure by integrating a dairy production system and an arable farm whilst maintaining the economic viability and without increasing N leaching.

Material and methods

A well-studied organic farm in Nagele is taken as starting point. This farm was started in 1977 as part of the Development of Farming Systems project (DPS) carried out by PAV (Praktijkonderzoek voor de Akkerbouw en Vollegrondsgroenteteelt, Lelystad). The farm is located in the Central Clay District of The Netherlands, where arable farming is the main agricultural activity. This arable farm imports large amounts of manure to maintain soil fertility. The soil is a young, well-drained, calcareous, sandy clay loam (fluvisol) with 2.7%

organic matter in the top soil. The 6-year crop rotation was: 1) ware potatoes followed by yellow mustard, 2) french beans, 3) celeriac, 4) spring barley undersown with white clover, 5) carrots and 6) peas undersown with ryegrass. For the calculations, the fields are manured with in total 18 t slurry ha^{-1} and 49 t farmyard manure (FYM) ha^{-1} over six years. The area of this small experimental farm (22 ha) is increased to 60 ha to arrive at a more realistic size of a mixed farm, for the purpose of this study.

The static model FARM is used for processing the basic data of the current farm and those of the designed mixed farm. These basic data describe soil (texture, organic matter content), climate (average temperature and length of the period of moisture availability), crops (area, yield, activities), animals (species, number, weight, growth, production, activities), feed rations, additional manure, equipment and buildings. FARM calculates nutrient balances, soil organic matter balance, feed balance (based on total digestible nutrients (TDN) and crude protein (CP)), nitrogen loss by volatilization, amount and composition of manure, labour distribution and economics. An earlier version has been described by Habets (1991). The current version in DOS, including a description of used formulas, is available from the authors. For the calculations it is assumed that only the basic operations (ploughing, preparing seedbed, harrowing, hoeing, mowing of grass) are done by the farmer, all other operations are done by contract workers. Data on variable costs and labour have been derived from Balk-Spruit & Spigt (1994). Costs for buildings have been estimated based on experience at adjacent farms.

The dynamic model NDICEA (an earlier version is described by Habets & Oomen (1993)) is used to calculate organic matter dynamics and availability and loss of nitrogen during a crop rotation. It includes a simple water balance to estimate soil moisture content and leaching. Mineralization of initial soil organic matter, and of the consecutive additions of residues and organic matter to the soil, are calculated using Janssen's one-parameter formula (Janssen, 1984) for the decomposition of organic matter with correction factors for soil moisture, temperature, pH and texture. The uptake of nutrients by crops is based on the intended or actual yield data and derived amounts of crop residues and roots. Nitrogen fixation by legumes is calculated based on a potential N_2-fixation and mineral nitrogen content in the top soil. Above a ceiling level for the soil-mineral nitrogen content, N_2-fixation is reduced linearly to zero at twice that value. Denitrification is based on the approach of Bradbury *et al.* (1993). Nitrogen leaching is calculated based on the excess of water, the amount of nitrate in soil and soil physical properties.

NDICEA was tested using data from the current organic arable farm, and the calculated values correlated rather well with the measured amounts of mineral nitrogen in top soil ($r = 0.74$) (Figure 1). The difference between calculated and measured amount of mineral N in the top soil seldomly exceeded 20 kg ha^{-1}. After soil parameters had been adapted in such a way that reality was described satisfactorily, the performance in the subsequent year was described quite reasonably (Van der Burgt, 1998). It is nearly impossible to check by measuring soil organic matter content over a period of six years whether the calculations are correct. In the further analysis it is assumed that the results of NDICEA can be used to evaluate the current arable farm and the designed mixed farm.

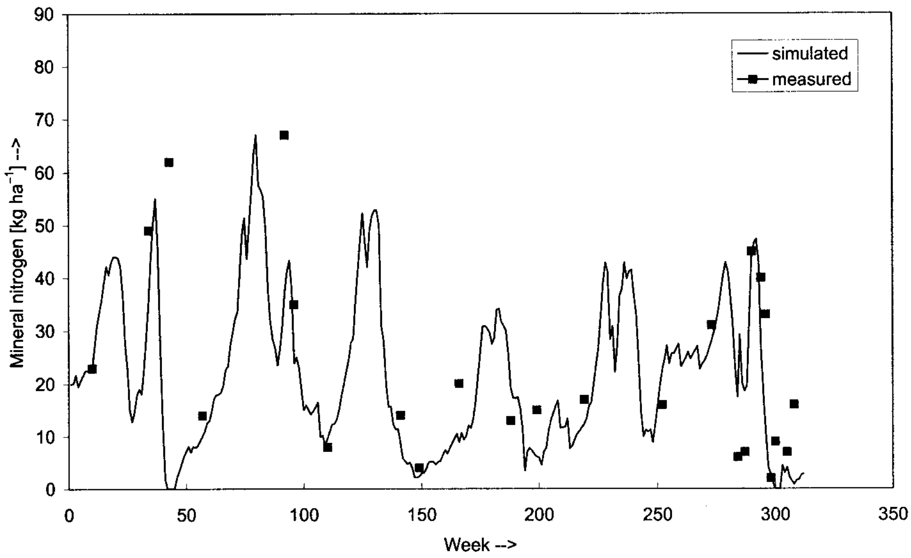

Figure 1. Calculated and measured amounts of mineral nitrogen in top soil (0-30 cm; kg ha^{-1}) during the 6-year crop rotation on the arable farm.

NDICEA calculates the dynamics within a crop rotation at field level, while calculations with FARM are based on the results of all fields on a farm in one year. They are combined by taking the results within a crop rotation as input of one year in FARM. This can be done when fields have the same size and soils have similar properties.

Re-designing the farm

Peas and beans in the current crop rotation have been replaced by two years of grass-clover, one year for mowing and one year for grazing. The N content of grass-clover exceeds the level of 2.5%, corresponding to a proper protein/energy ratio for dairy cows. This results in additional loss of nitrogen and burdens the liver of the animals. Therefore, spring barley has been replaced by whole grain silage of triticale to complement this protein-rich grass-clover. Winter wheat was grown to produce concentrates. The size of the herd and its milk production were adjusted to the amount and quality of available feed. Yield levels of crops were based on those at adjacent farms. Only the two crops with the highest economic return (celeriac and carrots) could be maintained. Using FARM, the amount and composition of manure was calculated, nitrogen loss by volatilization was estimated and the loss by leaching in pasture was calculated, assuming that neither dry matter production nor nitrogen content of the grass-clover pasture were affected by application of urine by animals. Moreover, on the whole farm 60 ton of urban waste compost and basic slag were applied.

After a first run using NDICEA, the manure had to be re-allocated and some yields had to be adjusted to the available nitrogen. Yellow mustard was replaced by a winter hard catch crop that could be ploughed in spring.

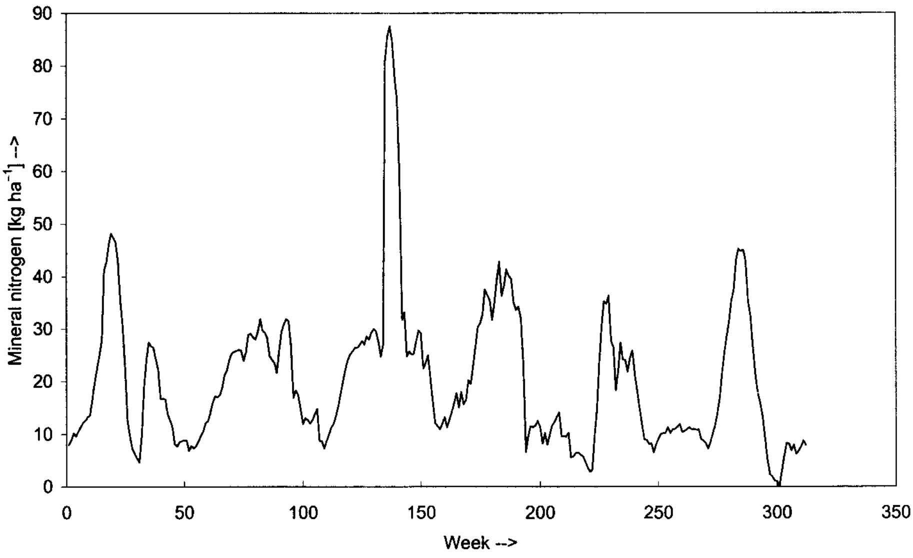

Figure 2. Calculated mineral nitrogen in top soil (0-30 cm; kg ha^{-1}) during crop rotation on the mixed farm.

Results and discussion

In the final design, 66% of the area is used to feed the animals (52 lactating cows plus corresponding young stock for replacement). This area of 66% fodder crops corresponds more or less with the current human consumption pattern (Oomen, 1995). The crop rotation is now: 1) whole grain silage, 2) grass-clover for silage making, 3) grass-clover pasture, 4) celeriac, 5) winter wheat + catch crop, 6) carrots.

In the designed mixed farm, all crops can absorb the nitrogen they need to reach the intended production level (Figure 2). The production level of grass-clover is assumed to be independent of the availability of soil nitrogen, as shortage is compensated by induced N_2-fixation. The yield level of celeriac could be maintained, that of carrots had to be adjusted (60,000 kg ha^{-1} instead of 68,000 kg ha^{-1}).

Table 1. P and K balance on the arable and the mixed farm (kg ha^{-1}).

	Input (kg ha^{-1})	Output (kg ha^{-1})	Balance (accumulation or weathering)
P arable	25	14	11
P mixed	13	13	0
K arable	49	107	–58
K mixed	9	73	–67

Table 2. Flow of available nitrogen on the arable farm (kg ha^{-1}), per corresponding period.

Crop	Week	Available	Fixation	Uptake intended	Uptake modelled	Denitri-fication	Leaching
Bare	1	35	0	0	0	4	7
Potato	17	118	0	122	122	14	19
Bare	32	33	0	0	0	6	−2
Yellow mustard	36	34	0	118	90	3	1
Bare	45	149	0	0	0	47	14
French beans	80	99	9	61	61	38	28
Bare	91	114	0	0	0	19	84
Celeriac	127	140	0	142	142	26	40
Bare	150	40	0	0	0	0	15
Spring barley	174	120	15	120	120	10	1
White clover	188	113	61	118	118	0	8
Bare	201	95	0	0	0	11	38
Carrot	230	149	0	155	155	15	13
Bare	250	47	0	0	0	3	8
Pea	278	155	102	195	185	8	−2
Bare	288	25	0	0	0	1	−1
It. ryegrass	290	141	0	165	151	25	8
Bare	311	2	0	0	0	0	0
Total	312	1609	187	1196	1144	230	279
Total kg ha^{-1} yr^{-1}		268	31	199	191	38	47

Table 3. Flow of available nitrogen on the mixed farm (kg ha^{-1}), per corresponding period.

Crop	Week	Available	Fixation	Uptake intended	Uptake modelled	Denitri-fication	Leaching
Bare	1	23	0	0	0	0	1
GPS	15	174	0	174	174	19	7
Grass-clover	32	105	44	97	97	0	5
Bare	52	1	0	0	0	0	0
Grass-clover	53	423	246	370	370	7	30
Pasture	105	564	216	353	353	66	129
Bare	176	14	0	0	0	5	2
Celeriac	179	163	0	114	114	37	41
Winter wheat	204	199	2	177	177	5	28
Black radish-Vicia	242	101	48	107	106	0	-
Bare	271	36	0	0	0	4	−1
Carrot	282	142	0	156	154	29	1
Bare	302	19	0	0	0	0	7
Total	312	1964	556	1548	1545	172	250
Total kg ha^{-1} yr^{-1}		327	93	258	258	29	42

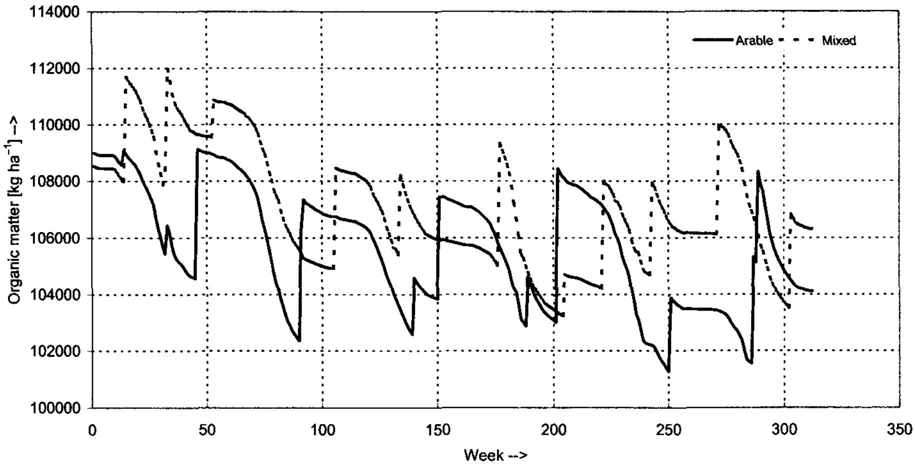

Figure 3. Calculated soil organic matter content in topsoil (0-30 cm; kg ha^{-1}) during crop rotation on the arable and the mixed farm.

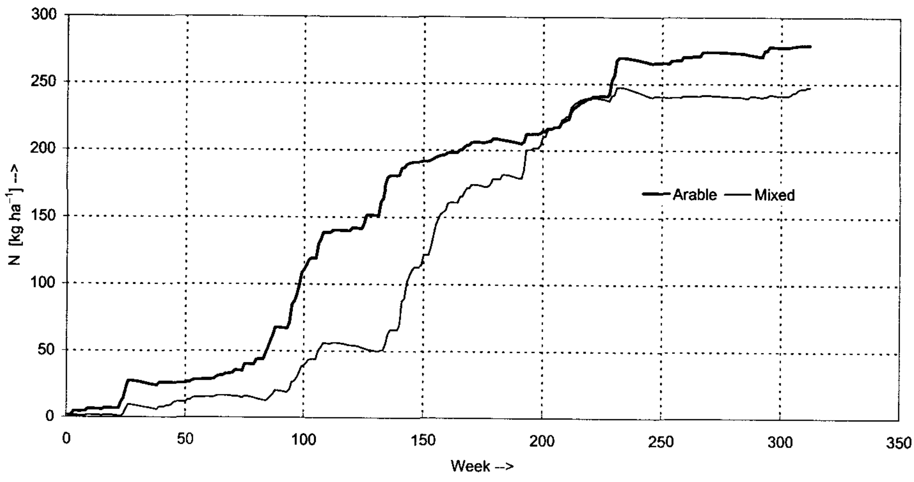

Figure 4. Cumulative N leaching (kg ha^{-1}) during crop rotation on the arable and the mixed farm.

Animals are offered feed with a proper protein/energy ratio in stable and consume a small excess of protein (9%) during the grazing season. Animal production is 8512 kg milk and 279 kg meat per hectare of fodder crops (including winter wheat).

Organic matter, P and K balance

On the current arable and designed mixed farms, the soil organic matter content is nearly constant. In the mixed farm, organic matter content is somewhat higher after one crop rotation (Figure 3). In the current arable farm the minor accumulation of P (11 kg ha^{-1}) is no

Table 4. Calculated economic results of an arable and mixed farm (Dfl $farm^{-1}$).

	Arable	Mixed
Gross margin crops	407805	251380
Gross margin animals		266695
Fixed costs minus labour costs	233374	309689
Economic result plus labour costs	174431	208386
Labour (h yr^{-1})	2650	5113
Income per hour	66	41

problem as the current P status is still moderate. Only the natural potassium resource is being mined, but net export of K (Table 1) can be replaced by weathering for a long time on this recently reclaimed marine sediment.

Nitrogen loss

In the current arable system as well as in the designed mixed system leaching losses (47 kg versus 41 kg N ha^{-1} yr^{-1}) exceed the aimed level of 33 kg N ha^{-1} (Tables 2 and 3). In the designed mixed farm more than 50% of the leaching occurs during the grazing period (Figure 4). The loss by volatilization (16 kg N ha^{-1} yr^{-1}) is at an acceptable level.

Economic results

Gross margin, fixed costs as well as economic result minus labour costs are higher for the mixed farm. On the mixed farm more labour hours have to be spent, but these hours are more evenly distributed over the year. On the arable farm there is underemployment during the winter period, but the income per hour is higher (Table 4). On the designed mixed farm, an equal income can be earned by working more hours per year.

Conclusions

On the designed mixed farm more people can be employed, the economic result per farm will increase and total leaching of N will decrease whereas both systems seem to be sustainable with regard to organic matter and P. Only the K resource is exploited.

Remarks on the re-designing process

The first outline was made based on theoretical knowledge and local experience. It could be improved substantially by using FARM and NDICEA. A similar approach might be used when networks of farms have to be designed. The final version is not necessarily the best one, another design might give better results. It may take quite more time to combine both models and communication between them should be automated to be able to evaluate more options at the same time.

Acknowledgements

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Decision support for mixed ecological farming systems based on physical product flows

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Introduction

This paper is part of a project that deals with a model approach to support the development of sustainable farming systems (see Wolfert *et al.*, 1997). Sustainability can be split into three dimensions: *economic*: farmers must have reasonable incomes, *ecological*: the quality of natural resources must be maintained and *social*: the farming system must be socially acceptable. Sustainability is a goal: 'mixed' and 'ecological' are technological ways to reach it. Mixed is defined as the integration of arable and animal production in one managed unit. Ecological is a synonym for organic. However, sustainability must be reached by interaction of the farmer with his farming system on one hand and with the ecological, economic and social environment on the other. This interaction is reflected in decision making in which self-reflection plays an essential role (Röling, 1994).

The desired model must generate and structure data to support decision-making on a mixed ecological farm to reach and maintain a sustainable farming system. Because of the self-reflection aspect, the model also has to function as a learning environment. Operational and tactical decisions have to be taken into account. Strategic decisions refer to changes in the kind of production system and are, therefore, outside the scope of the current model. This paper focuses in particular on modelling of the physical production process in terms of product flows.

Material and methods

The Ir. A.P. Minderhoudhoeve – an experimental farm in the Dutch Flevopolder – is used as a case study for the model. It is a mixed ecological farm of 90 hectares, integrating arable, field vegetable, roughage and milk production. More information about this farm can be found in Lantinga & Van Laar (1997) and Lantinga & Oomen (1998).

Figure 1 outlines the system layout from a decision-making point of view. The process informatics are the core part of the model, where the actual decisions are made. At the bottom, the physical production processes are defined in terms of primary processes that transform materials, life phenomena and energy into products and services. The physical flow model represents these processes in terms of data on inputs and outputs. It contains data that are relevant for decision making. Thus it acts like a data filter for the process informatics.

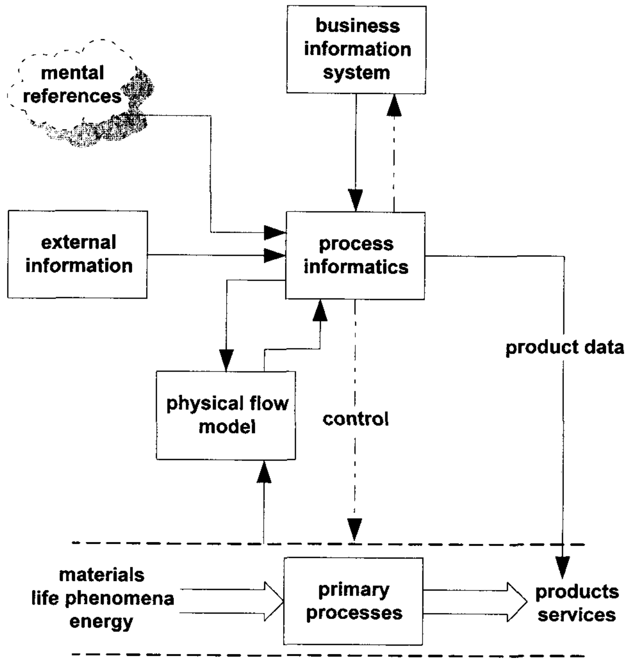

Figure 1. System layout. Except for the thick wide arrows at the bottom - those are *material* flows, all other arrows represent *data* flows. Further explanation in the text.

The physical production process is a dynamic process that forces the farmer to make decisions at certain moments. Filtered data from the process form the starting point. These are combined with external information (e.g. weather conditions, market prices) and business information. The business information system provides basic data like farm size, human resources but also business goals. These goals are farm-specific and have to be made explicit and quantified. The business information system is not yet worked out and will not be described in this paper.

In addition, the farmer will also use mental references, based on experience and tacit knowledge. This is often a very important factor in successful decision-making, but cannot be modelled. However, by saving decisions and their corresponding data in a 'historical database', an attempt is made to support the mentioned process of self-reflection. In this way the model doesn't only support actual decisions, but also supports the development of effective decision behaviour.

In addition to data analysis, a farmer – confronted with a range of possible decisions – often would like to carry out 'what-if-analyses'. This is a second objective of the physical flow model. Therefore, the physical production process is modelled in terms of product flows using a multi-input-multi-output (MIMO) approach (Jansen, 1998). This approach splits up the complete production process into several units, where each unit can be

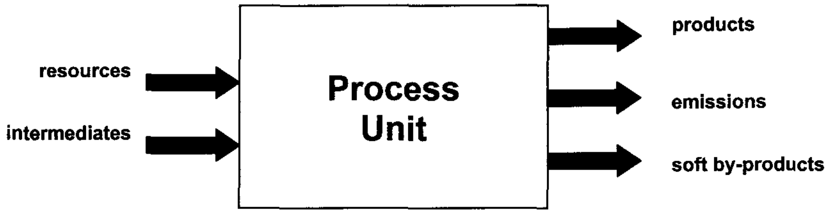

Figure 2. Basic layout of multi-input-multi-output (MIMO) process unit. Further explanation in the text.

uniformly described as a black box with multi-input and multi-output (Figure 2). At the input side resources and intermediates are distinguished. Resources can be either energy or materials (e.g. nitrogen). Intermediates are products from a preceding process unit. At the output side products, soft by-products and emissions can be distinguished. Products can be either end products leaving the farm or intermediates for a subsequent process unit. Soft by-products are products that are not input for another unit, but quantifiable indicators for 'products' such as animal welfare, aesthetic values, etc. Emissions are all other material flows that are returned to resources, for example N leaching to the N supply. A software tool called Visio[1] is used to visualize all relevant process units and product flows in diagrams using an object-oriented approach. This means that all processes and flows are represented by objects that have their own properties and methods (Booch, 1994). One important advantage is that all data of the Visio diagrams can be stored in a database. This database will be used as a source for program code. In this way, consistency between program code and diagrams is assured.

After the farmer has combined all relevant data and done several 'what-if-analyses', a decision is translated into a control event. Control will affect the actual physical production process and also business information.

Besides supporting management, this approach will also collect much information about the end products, their substance and how they are produced. This links up with the trend of certification in which this is a main prerequisite.

Results and discussion

The Ir. A.P. Minderhoudhoeve farming system (Lantinga & Van Laar, 1997) was divided into several main production lines: milk, potato, bakery wheat, onions, cabbage and several other small vegetable crops. These production lines have been modelled in terms of connected MIMO process units. All process units and flows are visualized in one drawing. However, Visio enables to distinguish different layers that can be visualized, separately. Each production line is assigned to a separate layer. Within a production line, the following sublayers are distinguished: product flows, internal resource flows and emission flows.

[1] Visio Corporation, 520 Pike Street, Suite 1800, Seattle, Washington 98101, USA. www.visio.com

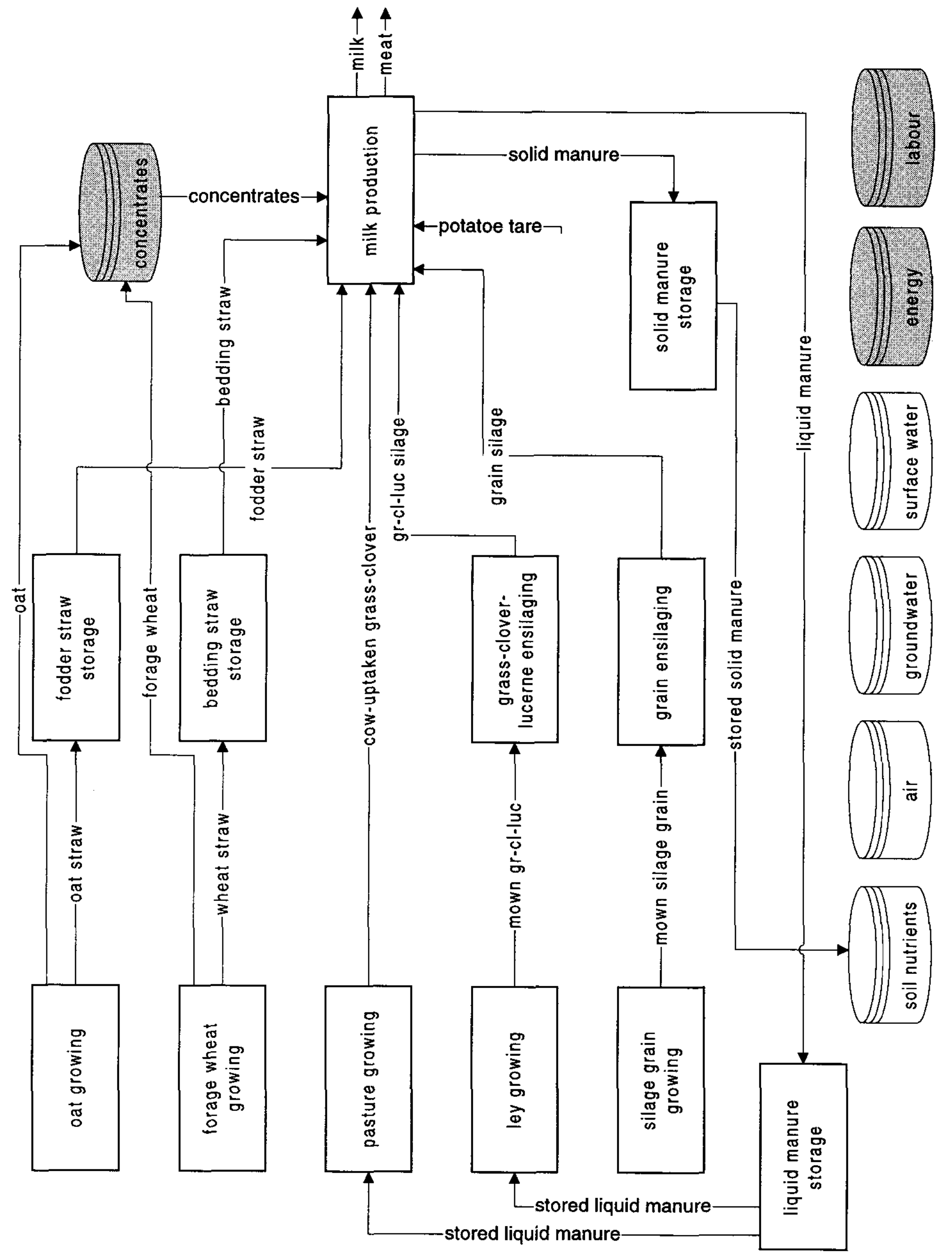

Figure 3. An example of a production line (milk production) modelled in terms of product flows. Rectangles represent process units. Drums represent internal (transparent) and external (grey) resources. Only main product flows are shown.

Figure 3 shows the product flow layers of the milk production line. Division of process units was based on geographical distinguished units e.g. fields, stores and stable. The principle behind this is that it links up with the farmer's view on his production system in reality.

Internal resources are defined at whole farm level: soil nutrients, air, groundwater and surface water. Each internal resource can be subdivided in subresources. The resource soil nutrients, for example, can be distinguished in nitrogen/phosphorus/potassium. External resources are assigned to each specific production line. A special external resource is energy. It doesn't make sense to draw energy flows because all process units use energy. Energy use is, therefore, a fixed attribute of a process unit.

Thus several separate production lines can be distinguished. However, the basic principle of mixed farming is to combine these lines to recycle products as much as possible. Assigning a flow to multiple layers does this. For example, *potato tare* is a primary flow of the potato production line. Potato tare is fed to cows and thus it becomes a flow of the milk production line (see Figure 3).

One of the next steps is to attach quantitative data to flows and process units. What data are defined depends on the specific goals of the farm. For example, one goal may be: no depletion of the N resource. Therefore, all incoming and outgoing flows of this resource must be quantified and the net flow must be zero. However, a main problem is the availability of data, because it is often not feasible, technically or economically, to measure continuously and with infinite accuracy. There are three possible solutions to tackle this problem (Jansen, 1998): (*i*) use of norm values, based on earlier experiences or estimations, application of norm values obliging the application of spreading to determine the level of accuracy; (*ii*) use of computations, for example for volatile substances by calculating the mass balances of relevant inputs and outputs; (*iii*) use of measurements, for example, sampling of silage feed.

Furthermore, the model must be dynamic. First, data must be updated at certain moments and secondly it must be possible to carry out 'what-if-analyses'. The latter function requires definition of transformation functions on input-output relations. These have to be kept as simple as possible. 'What-if-analyses' don't have to provide exact forecasting, but must indicate directions.

In addition, soft by-products for each process unit have to be defined quantitatively. This approach, called 'enterprise resource planning' originates from process industry. Looking at one production line there is convergence of inputs with regard to the main products, but divergence with regard to wastes, emissions and by-products. In highly specialized industry, such as factory farming which is comparable to intensive agriculture, this convergence results in high amounts of – often undesired – output. In a mixed farming system where natural resources are an essential part of the system this is not the case. In reality, these natural resources also exist in specialized farm situations, but then they fall outside the scope of farm management. We might conclude that this approach results in a more sustainable management of natural resources.

A main difference with industry is that we are not dealing with man-made machines, but ecological systems with their own autonomous regulation. This makes them less controllable. That doesn't represent a principal difference in model composition, but will make its development more heuristic.

An illustration of a decision

In Figure 3, we see many inputs in the milk production process unit. At certain moments the farmer has to decide how to feed the cows on the basis of an economic main goal of a certain production. Besides, he will have other goals, on e.g. the quality of the manure produced, cow welfare and ammonia emission. From experience and other references he knows in terms of protein, energy and feed structure the approximate input for the cows. First, information must be collected on the amount and quality of available feeds. On the basis of this information he carries out some 'what-if-analyses' and is confronted with the possible consequences regarding his goals. Then he will make a certain decision that is optimal in his opinion. (So, the model is only supporting (Decision-Support-System) and doesn't dictate the optimal decision. This leaves room for specific styles of farming.) The decision will influence the production process: stocks decrease, processes are put into motion and indirectly this will influence the physical flow model.

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Modelling mixed farming in a spatial continuum

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Modelling in a spatial continuum

The growing concern on major environmental problems such as eutrophication and acidification in areas with concentrations of intensive livestock production has evoked renewed interest in problems of optimal spatial allocation. Introduction of mixed farming, that could combine improved distribution of livestock production with reduced nutrient use, has been proposed as a method to alleviate emission effects of existing animal husbandry practices. Problems to be solved with respect to the introduction of mixed farming include the determination of optimal size, number and distribution of stables (or 'livestock plants', i.e. buildings and all facilities and equipment around it) over a given area, and optimal nutrient use in crop and livestock production. The stables can be considered as separate livestock farms, or as part of mixed farms that are to be established in a given region. For convenience, they will be referred to here as farms.

So far, the wealth of geographical data on climate, soils, land cover and groundwater flows that increasingly have become available through remote sensing, has mainly been incorporated in Geographical Information Systems, which can produce highly detailed maps, but so far contain only few and very simple decision support tools to optimize over a spatial continuum. As a rule, the geographically explicit decision models either describe a separate optimal decision at every point on the map, without accounting for spatial interdependencies, or are limited to optimization over a relatively small number of regional units, strongly at the expense of geographical detail.

Optimization over a spatial continuum has been studied in location theory, where it is discussed in connection with the problem of optimal facility location. Such problems usually amount to finding the geographical location of an industrial facility that minimizes the cost of transporting goods to that location from a surrounding region or vice versa. The early location models are classical transportation models and only select the best out of a finite number of alternatives and treat the region as a finite number of fields, identified by their barycentre (see e.g. Beck & Goodin, 1982, for an application to dairy farms). Subsequent location/pricing models treat the site as a continuous choice variable and simultaneously calculate the consumer price at every point in the region on the basis of the distance from the facility (Hansen *et al.*, 1987; Drezner, 1995).

The question of optimal land use does, however, require a broader treatment. It calls for an explicit spatial representation of land use itself, with land being allocated to competing uses, so as to maximize, say, the total revenue in the region, as opposed to the cost minimization of the location/pricing models. This introduces two methodological challenges. The first issue is the representation of optimal allocation in a spatial continuum. This naturally leads to models containing integrals over space, which in general cannot be solved analytically, in view of the variability in the underlying GIS-information. The second issue is that the resulting model, which combines optimal routing and profit maximizing decisions by individual producers, with market clearing at regional level, requires solving nested optimization problems.

Both issues are addressed by Keyzer & Ermoliev (1998). Their paper specifies regional models in which profit maximizing producers operate within a spatial continuum and compete for land and commodity markets. Their models are associated with a decentralized, stochastic procedure for attaining the (global) optimum. The procedure is a stochastic quasi-gradient (SQG-) algorithm as was described by Ermoliev & Wets (1988). The main technical difficulty that is addressed is to deal with a (spatial) integral in the objective of a convex program.

Mixed farming

The paper applies this approach to a model of mixed farming. This allows optimization where livestock farms with stables at discrete locations interact with crop production on fields in a spatial continuum, and focuses on the effects of ammonia emission that spreads over the neighbouring environment, and reduces crop output. The decision problem is to confront each livestock farm with the (continuum of) land users in its neighbourhood (actually in its environment) who suffer from the emissions, i.e. to maximize total income or welfare of the region while internalizing the environmental effects, and this naturally requires optimization over a spatial continuum. Polluting livestock farms will provide compensation to the land users. This will affect their profitability, and size of operation at each site, as well as the revenues and cropping patterns of the land users around them.

Spreading of cumulative emissions of a given pollutant is represented via two-dimensional density functions. These are defined over the relevant geographical region and measure the incidence (fraction) of pollutant emitted by a stable or an intensive livestock farm, located at a given site that deposits at each point in the region. If the emissions consisted only of pollutants such as nitrous oxide or carbon oxide gases, that tend to dissipate quickly into the atmosphere, the analysis could focus on reduction of aggregate emissions, and there would be no need for a local study. However, most emissions from livestock production have a definite local component, whose cumulative effects depend on location-specific factors such as soil type, slope, crop cover and climatological factors.

From the definition of the model, it follows that revenues of a crop farmer from livestock production activities will increase with (*i*) the level of emission, (*ii*) the dispersion density to location x, and (*iii*) the marginal damage at location x. Conversely, each stable owner will have to restrict its emissions (and possibly even close down), if its pollution dissipates to locations x where the damage is important, either because the location itself is vulnerable or because other stables can pollute it more profitably (i.e. can obtain more revenue from a marginal unit of pollution). Therefore, the model can be interpreted as a location model, even though location is fixed. The model applies a Stochastic Quasi-Gradient (SQG-) process. The algorithm considers a sequence of random drawings from location x(t), and starting from a given emission level, where actual emissions are adjusted according to an optimization rule (for details, see Keyzer & Ermoliev, 1998). From the general results of the convergence of SQG-methods it follows that if requirements on behaviour of the revenue functions are fulfilled, the model process converges with probability 1 to the desired optimum.

Application to ammonia emissions

The model will be applied to a fictitious area, with soil types that show differences in optimal land use (crops cultivated and associated nutrient input level), as well as in sensitivity to damage to acid deposition. Livestock production is characterized by a revenue function that relates revenue to emissions of ammonia. This function will be estimated using information from Central Europe. Emissions are calculated by means of a balance sheet approach, as the difference between nitrogen in feed and that in the products. The remainder is considered to be recovered in the manure. Emissions are calculated as a fraction of manure-nitrogen as described in literature (Van der Hoek, 1994). Transport and deposition of emissions is represented by a logarithmic function derived from a figure depicting ammonia transport taken from Asman & Van Jaarsveld (1990).

Crop revenue is taken as fixed at any point in the area. Damage due to deposition of ammonia salts will be depicted by its effect on the soil organic material store. It has been described (Van Breemen & Van Straaten, 1991), that acid depositions lead to the deterioration of stable soil organic matter. While this results on the short-term in a declining organic matter store, effects on the long-term are much more severe: increased aluminium toxicity, leading to reduced root growth and increased sensitivity to drought, as well as to reduced natural fertility and increased leaching of nitrate. After the buffering capacity has been used, depositions thus directly affect crop yield. This will be depicted by calculating the value of additional fertilization required to compensate reduced crop growth and revenues.

Conclusion

Representation of an area as an continuum, as has been discussed here, has several advantages. Problems of spatial allocation now can be optimized combining discrete (livestock production) with continuous (crop cultivation) aspects of land use in a maximization of total revenue for a given region. Alternative technologies of livestock production can be represented by means of various revenue functions: if the livestock farms operate under decreasing returns, the optimal choice can be made endogenously, but if increasing returns prevail, the choice has to be made by comparing alternative scenarios.

Once an optimal emission value has been estimated, GIS-tools allow to produce, say, 'altitude' maps of farm revenues at a given point in the area. Furthermore, model results can be compared in a spatially explicit manner with the result from an alternative, two-stage procedure in which the permits have zero price and the stable owner maximizes its revenue, while the land-users are confronted with given pollution levels but do not receive compensation. By simultaneously evaluating the revenues from livestock production and from affected crop cultivation, the model allows analysis of the effects of internalization of environmental costs.

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FASSET - A dynamic whole farm simulation model

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Introduction

In recent years, society has requested more research in the environmental and economic implications of changes in both the environmental and the agricultural policies. A balance between economic development and environmental conservation has to be found and research should provide information to support political decision-making.

Loss of nitrogen from the farm to the environment and the use of pesticides in arable farming are major components of negative environmental impact. The government in Denmark has, therefore, issued action plans on nitrogen (N) and pesticide use. The action plan on nitrate aims at reducing nitrate leaching from agricultural land by 50% (Jensen *et al.*, 1994). The action plan on pesticides aims at reducing pesticide use by 50%, both in terms of amount of active ingredients and in terms of treatment index (Jørgensen & Secher, 1996). The original deadlines for meeting the targets have not been met.

Research is now increasingly being focused on environmental issues to reach these aims and to make farming systems sustainable. This research is often concentrated on solving specific problems and elucidating specific processes. However, it is important that results at this detailed level are interpreted in a wider context (e.g. farm level) to evaluate consequences of changes in management or policy.

This paper describes a whole farm model aimed at evaluating consequences of changes in regulations, management, prices and subsidies on a range of indicators for sustainability at farm level, e.g. farm profitability, production, nitrogen losses and pesticide use (Olsen *et al.*, 1996). The model is currently implemented for an arable farm and a pig farm.

Material and methods

The structure of the farm model has been formalized using object-oriented design methods (Yourdon, 1994), and has been implemented in C^{++} (Stroustrup, 1991). The use of object-oriented programming enables a safe re-use of the program code (Olesen *et al.*, 1996). The soil simulation model of the crop rotation component is thus also used within another modelling context (Olesen *et al.*, 1997).

The conceptual model structure is shown in Figure 1. From a dynamic point of view the model has two components, a planning model and a simulation model. The simulation model is largely identical to the 'Farm system' in Figure 1. The farm is considered to have two biological components: livestock and arable fields. These interact directly or through the

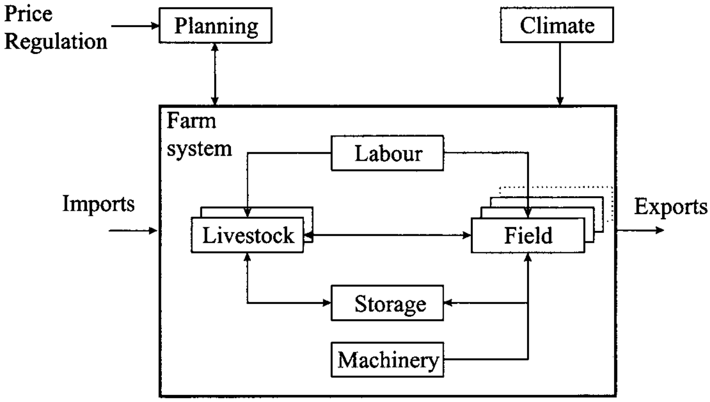

Figure 1. Conceptual structure of the farm model.

storages, which may contain fertilizer, animal manure, feed stuffs, etc. A plan for the operation of each component in the farm system is issued by the planning component, and the results are stored in a large set of indicators. The model is run on a daily basis starting on 1 September each year.

The planning model comprises a linear programming (LP) model, that optimizes farm income given a set of external conditions. The criteria function is only based on farm profit. However, risk aversion and other criteria may also be included. A three period LP-model is used to account for the proper time frame of planning a crop rotation. A one period LP-model is used to optimize fertilizer and pesticide use. The outcome of the LP-models is a plan for the subsequent production year including crop choice, schedules for applying fertilizers, pesticides, etc. for each field and feed plans for the livestock. Planning is carried out once a year. The technical coefficients for the LP-model are generated by the individual components in Figure 1 and depend on the state variables of these components. Crop choice and yield levels are thus dependent on the cropping history of individual fields (Jacobsen *et al.*, 1998).

The simulation model simulates the outcome of the production plan, using measured weather data from 1961 to 1995. The state variables of each model object and the flow of products and information between model entities are updated in daily time steps. The model contains various product flows. The most elaborate product flow refers to N (Figure 2). Nitrogen is imported into the farm as livestock, artificial fertilizer or feed stuffs, and exported in plant or animal products. There is also import of N to the fields as atmospheric deposition and as N_2-fixation. Losses occur through nitrate leaching or gaseous losses of ammonia, nitrous oxide or free N. These data form the basis for calculating a farm N balance (Olesen, 1996).

The buildings on the pig farm are assumed to have a fixed maximum capacity and pigs are assumed to be exported at a specific weight. Manure stores also have a maximum capacity, which affects the schedule for manure application to the fields. Ammonia may be

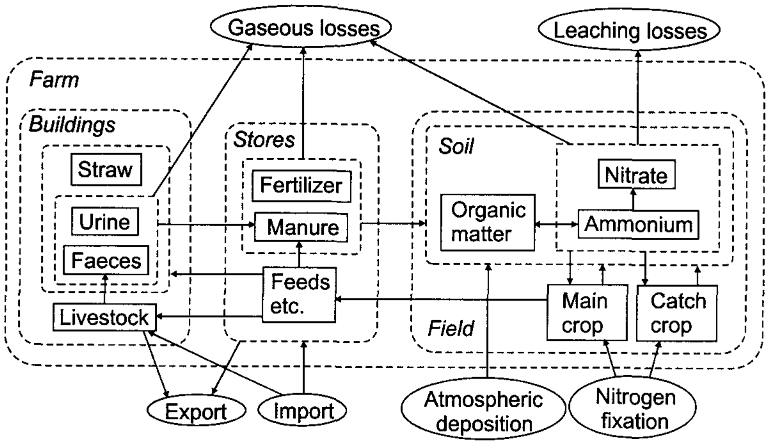

Figure 2. Nitrogen flows on a pig farm.

lost from all parts of the system through volatilization. This is calculated using the principles proposed by Hutchings *et al.* (1996).

The crop simulation model calculates dry matter production from estimated light interception, multiplied by a radiation use efficiency that depends on temperature, crop nitrogen status and water availability (Petersen *et al.*, 1998). Light interception is calculated from leaf area which is simulated using expansion rates depending on crop phenological stage, temperature, N availability and soil water status. Nitrogen fixation is assumed to depend on growth rate and crop N deficiency.

The soil part of the model has a one-dimensional vertical structure, and is divided into a number of layers. The hydrological processes considered include accumulation and melting of snow, interception of precipitation by the crop canopy, evaporation from crop and soil surfaces, infiltration, water uptake by plant roots, transpiration and vertical movement of water in the soil profile. Soil temperature and ice formation are described. Soil water and N movement are modelled by a combination of the simplified approach described by Addiscott & Whitmore (1991) and the Richards equation (Hansen *et al.*, 1991). The N transformation processes in the soil model are net mineralization, nitrification, denitrification and N uptake by plants. The N turnover model is identical to the one used in the DAISY model (Hansen *et al.*, 1991).

The economic part of the model calculates the gross margin as revenue from sold products minus variable costs, including seed, imported fertilizer, pesticides, fuel, etc. Prices can either be given beforehand or based on Monte-Carlo simulation of the actual prices using a triangular distribution (Lund, 1987). The profit before labour and capital costs is calculated as the gross margin minus maintenance, depreciation and insurance. The use of labour and machinery in the different operations, both in the field and in the buildings is also taken into account. Based on an imputed labour cost, the return to capital can be calculated.

The model is furthermore able to update the expected prices for the following period, using either naive, adaptive or rational price expectations (Romstad, 1993).

The model is presently able to simulate an arable farm or a pig farm. The following crops are presently available in the model for both farm types: winter wheat, winter barley, winter rape, spring barley, peas and ryegrass (for set-aside).

To separate the transient effects from the long-term effects of imposing regulatory changes, each simulation was carried out for 35 years. In addition each year in the simulation run was simulated for 10 different climatic conditions to average out the effects of weather on productivity and nitrogen losses. The model was run for a 75 ha pig production farm (125 livestock units) on a sandy loam. Data from the climate station at Ødum (56°18'N, 10°08'E) for the period 1961 to 1995 were used. The farm was assumed to have ten fields initially.

The model was used to evaluate effects of different N taxation scenarios:

- Base scenario, no taxation.
- A tax of 5 DKK (100%) on nitrogen in artificial fertilizer.
- A tax of 5 DKK on farm N surplus, i.e. N imports minus exports. Imports considered are fertilizers, feed stuffs and expected N_2-fixation. Exports comprise all plant and animal products exported.

The tax was introduced 15 years after running the base scenario. Each scenario was evaluated using the following sequence of model runs:

1. A specific farm type is selected (including initial set-up of farm area, soil types, weather file, farm history, buildings, machinery, etc.) and the base scenario is specified.
2. The first year from the set of weather conditions (e.g. 1961) is selected.
3. The LP-model makes a plan for the next growing season.
4. The consequences of the plan are evaluated using the simulation model.
5. The next weather condition is then selected.
6. Steps 3 to 5 are repeated for 35 years. When the final year in the weather files has been reached, the next file is that from the first year again.
7. To create a new complete run, based on the same plan, but with different weather conditions, the starting year in the climate file is advanced by three years.
8. Steps 4 to 7 are repeated 10 times, using the original production plan from the LP-model.
9. The resulting indicators are averaged over the 10 repeated runs.

Results and discussion

The average values of a range of important indicators for the last 20 years in the 35-year scenario period are shown in Table 1. The results show marked differences in many indicators, depending on the taxation scenario used. Changes in crop rotation are mainly related to winter rape and pea area. The set-aside area of 9% was unaffected. The highest reductions in imports of mineral fertilizer and feedstuffs follow a fertilizer tax, and the feed import actually increases with a tax on N surplus. This import is needed to compensate for the smaller pea area. Nitrate leaching is reduced in both taxation scenarios, but ammonia

Table 1. Average results over the last 20 years of a 35-year period for three nitrogen taxation scenarios for a 75 ha pig production farm. Both taxation scenarios use a tax of 5 DKK kg^{-1} N. All losses refer to the farm as a whole, but are specified on a per area basis.

Indicator	Base scenario	Fertilizer tax	Tax on N surplus
Spring cereal area [%]	0	0	1
Winter cereal area [%]	63	64	71
Winter rape area [%]	19	14	20
Pea area [%]	9	14	0
Import of mineral fertilizer [kg N ha^{-1} yr^{-1}]	20	0	10
Import of feed stuffs [kg N ha^{-1} yr^{-1}]	207	202	215
Farm nitrogen surplus [kg N ha^{-1} yr^{-1}]	125	113	111
Nitrate leaching [kg N ha^{-1} yr^{-1}]	68	58	54
Ammonia volatilization [kg N ha^{-1} yr^{-1}]	77	75	76
Denitrification [kg N ha^{-1} yr^{-1}]	1	1	1
Farm profit before capital and labour [DKK]	1,640,000	1,637,000	1,591,000
Tax [DKK]		89	43,000
Cost of reducing N leaching [DKK kg^{-1} N]		4.3	5.8
Cost of reducing N loss [DKK kg^{-1} N]		3.4	5.1

volatilization and denitrification are almost unaffected.

Average nitrate leaching in Table 1 is almost identical to that obtained using an empirical model for nitrate leaching on a similar soil type and under similar crop rotation and N application regimes (Simmelsgaard, 1998). Ammonia volatilization on this farm type is higher than nitrate leaching, and this difference increases in the taxation scenarios. In contrast to nitrate leaching, ammonia volatilization is mostly affected by the type of housing, slurry storage and field application techniques, which depend on farm investments. These variations in farm characteristics can not currently be handled by the LP-model in FASSET.

A 100 % tax on N in mineral fertilizer decreases the use of mineral fertilizer on average by 20 kg N ha^{-1}, but nitrate leaching is only reduced by 10 kg N ha^{-1}. The amount of animal manure produced on the farm and available for field application constitutes 132 kg N ha^{-1} and can not be sold, hence the total amount of N applied in some years is higher than optimal. The shadow price of nitrogen is in this case equal to zero. The change in farm profit (before capital and labour) is approximately 2,900 DKK in the case of a fertilizer tax, when the tax revenue is transferred back to the farm. The cost of a fertilizer tax can also be expressed as 4.3 DKK per kg reduction in nitrate leaching. A similar tax on N surplus resulted in lower nitrate leaching, but at a slightly higher cost. The latter scenario is, however, often considered more fair, as the farms with the highest nitrate leaching would pay the highest levy. The fertilizer tax will have substantial distributional effects, which is not addressed in the model.

Vatn *et al.* (1996) used a similar model to evaluate measures of reducing nitrate leaching in Norway. They excluded, however, livestock from their model. They found that a nitrogen tax was one of the most economically efficient ways of reducing nitrate leaching, costing 9-14 DKK kg^{-1} N. The cost of reducing N leaching was considerably lower in this study (Table 1), which may be the result of many factors, including farm type, management and climatic conditions.

Smith *et al.* (1997) used a N simulation model to investigate effects of changes in crop rotation design on nitrogen losses. Their results showed that up to 43 kg N ha^{-1} yr^{-1} could be saved just by changing the order of the crops. FASSET using an LP-model to optimize the structure of the crop rotation, also includes considerations on N savings. This approach allows evaluation of the consequences of changes in prices and regulations. The current results demonstrate that different nitrogen taxation policies may have profoundly different effects on the farm system and on N losses.

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Socio-economic determinants of mixed farming systems

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Introduction

Farm management research traditionally has had an interest in the organization of production at farm level and thus in farm structures, such as specialized and mixed farming. This interest originates in the work by Aereboe (1917) and Brinkman (1922). These authors laid the foundations for the concept[1] that farm structures are the result of the interactions between *integrating* forces (e.g., agronomic requirements of crop rotation, risk management, costs of trading and transporting) and *differentiating* forces (e.g., scale advantages in terms of costs and knowledge). Integrating and differentiating forces are exerted by external determinants (market situation, environmental policy, technical developments), internal determinants (technical and financial status of the farm, quality of management, family situation) and the physical environment (soil type and fertility, soil hydrology, climate, etc.). A further assumption in farm management research is that the individual farm manager will adapt the existing farm structure when changes in the external, internal and natural environment occur to ensure his goals and objectives. This is known as the concept of the 'adaptive man', see Cyert & March (1963); Day (1975, 1976); Brandes (1985). The dynamic framework of Structure-Conduct-Performance[2] (SCP) in Figure 1 combines both concepts.

Depending on the relative magnitude of the integrating and differentiating forces, farms will specialize to a certain degree. A change in the relative magnitude of these forces over time, therefore, implies that a new balance has to be established through adaptation of the farm structure[3]. During the last decades, the dominating factors were the differentiating forces and these activated a process of rationalization, growth and specialization. This process, however, has become an issue of scientific, public and political debate because of

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[1] Schmitt (1985) illustrates the completeness of this body of thought by showing that the well-known transaction cost theory of Coase (Coase, 1937; Williamson, 1981) can be looked upon as one of its an elements.

[2] The Structure-Conduct-Performance (SCP) concept originates from analysis of industrial organization (Bain, 1968). For a recent review see Clarkson & Leroy Miller (1982), for instance. Van Dijk *et al.* (1986) discuss the use of the SCP framework for the analysis of agricultural change in developed countries.

[3] With regard to agriculture the word 'structure' is used in two senses, that are interrelated (Petit, 1976). At the farm level, structure is defined by the quantities of various input factors and by input-output relationships. Hence, farm structure in a micro-economic sense, is closely related to the state of technology and to natural conditions (Van Dijk *et al.*, 1986). The structure elements at farm level are the basis for the structure at sector level. The overlap consists of elements such as farm size, level of specialization and mechanization, financial status, etc. Economic structure, applied to the entire sector relates to size, number and location of farms and with the basic spatial, organizational and institutional characteristics of the sector. Structure at sector level further includes the size and (age) composition of the working population, the level and type of mechanization, and the organization of marketing and distribution.

negative side effects such as surplus production, deterioration of the agro-ecosystem and pollution. This has led to environmental regulations, increasing consumer demands with respect to food safety and animal welfare, and research on more environmentally friendly production methods. This new constellation of forces has induced renewed interest in mixed farming systems.

Integrating and differentiating forces can be studied from two points of view in farm management research. The *normative* approach is to analyse the *optimal* farm structure. Plans of farm structure and organization of production are developed according to the principle of profit maximization. Such plans are based on insights derived from technical disciplines on the production-ecological and environmental-ecological characteristics and interrelationships of various production techniques. The alternative, *positive* or socio-psychological approach is to start from the farmer as a decision or choice maker. Differences among farmers and differences between actual and optimal behaviour following from normative research are studied, in particular. So, here the focus is on *actual* behaviour.

The positive and the normative approach in farm economics should be considered complementary, rather than as alternatives. An outline is given how to apply the two approaches in mixed farming systems research. The situation in the region of Flevoland where the 'Ir. A.P. Minderhoudhoeve' experimental station is located, is taken as a case study.

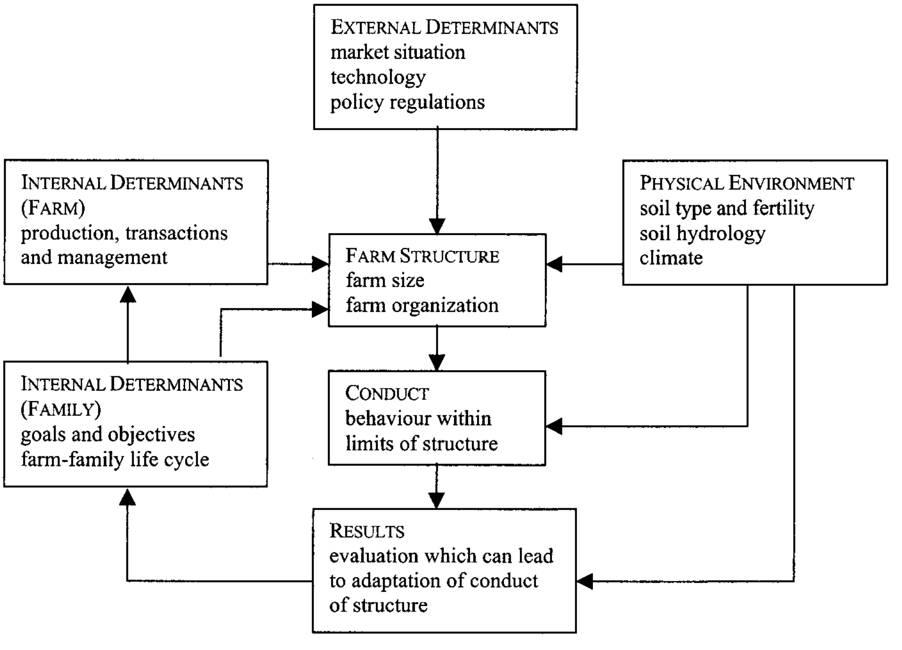

Figure 1. Farm structure and structural changes at farm level. Source: Wossink, 1994.

Project 1: Positive economic analysis of mixed farming systems

Objective

The first project has a fundamental orientation. Goal is to develop an analytical model from the literature on integrating and differentiating forces and to apply this to mixed farming systems. More specifically, the project will address the following questions:

- According to the literature, what are the integrating and differentiating forces at the family farm level and what determines their weights and their interrelationships?
- How can these insights be combined in one analytical model to quantify the weights and interrelationships of the integrating and differentiating forces?
- Which methods and techniques are suitable to apply this analytical framework? What are the outcomes when applied to mixed farming for field crop and dairy farms in Flevoland?

Method and data

Hoff (1994) presents a theoretical model of farm structure selection based on minimization of the costs of production, transaction and management. If the integrating and differentiating forces change, the costs will be affected and an alternative farm structure might become preferable. Central to the model by Hoff is the assessment of the critical values of the costs at which switching from one farm structure to another takes place.

Hoff's model only considers tactical considerations. Switching of farm structure, however, can be expected to include major strategic considerations. Strategic behaviour of farmers and other entrepreneurs is largely based on their perception of future options, see Dixit & Pindyck (1994). The theory of option pricing or contingent claims (Black & Scholes, 1973; Merton, 1973) offers a suitable framework to include the total of transaction, production and management considerations and the role of uncertainty and perceptions of strategic alliances.

Estimation of the static Hoff-model by means of factor analysis of farm accounting data is the first step in applying the insights above to mixed farming – these data should cover multiple types of farm structures for this specific purpose. The second step is to elicit farmers' preferences and perceptions of different types of mixed and specialized farm structures by means of interviews. Such a survey enables assessment of the subjective attributes of mixed and specialized farm structures and their weight by the individual farmer. The final step is to analyse the strategic considerations by means of a computer-directed workshop based on game theory. This should give insights in the perception of farmers regarding their own behaviour and that of their colleagues with respect to mixed farming under alternative scenarios of future conditions. Dairy and field crop farmers from Flevoland will be invited to participate in this workshop.

Project 2: Normative economic analysis of mixed farming systems

Mixed farming can take place in many different ways. Characteristic is a connection between animal and crop production. This connection can be organized within one agricultural firm by combining several branches sharing resources and management. An alternative way is collaboration between two or more farms that exchange inputs (land, machinery, labour), but not management: the individual farms remain autonomous. The most far-reaching way is merging separate animal and crop enterprises into one production unit: then management is shared as well.

Objective

Objective of the normative project is to develop a method to explore possible changes in the regional agricultural structure of Flevoland, considering the different forms of mixed farming described above. Special attention will be given to the environmental advantages of mixed farming. More specifically the following questions will be addressed in Project 2:

- What are concrete possibilities for different forms of mixed farming for the field crop and dairy farms in Flevoland. What are their financial and other economic and environmental results under different scenarios of environmental policy?
- What is an appropriate method to simulate the development of future regional agricultural structure?
- What is the possible impact of mixed farming on the regional agricultural structure in Flevoland compared to the situation without mixed farming for the period till 2010?

Method and data

Mathematical programming methods are well suited for the assessment of optimal farm plans, because: (a) many activities and restrictions can be considered simultaneously, (b) an explicit and efficient optimum-seeking procedure is provided, (c) once formulated, the results from changing variables can be evaluated easily and (d) new production techniques can be incorporated by adding additional activities to the model. Particularly the possibility to investigate detailed technical and environmental questions makes the mathematical programming technique an attractive approach.

It would be very time-consuming to develop a farm model for each individual farm in Flevoland. When using the programming technique, one approach is to break down the relevant population into a number of categories of farms and to model a representative farm type for each category. New developments in this field are the use of Maximum Entropy estimation (Golan *et al.*, 1996; Paris & Howitt, 1997) and of frontier technology assessment (Jonasson & Apland, 1997). Another option is to use a sample of individual farms in the population; see Boorsma (1990). Regardless of whether representative or sample farms are used, special attention has to be given to validation of the farm models. Recently, Positive Mathematical Programming has been introduced to make programming models represent the base situation precisely (Howitt, 1995).

Linear programming models can be combined with (non stationary) Markov chain modelling to simulate changes in regional agricultural structure, accounting for interaction among farms. Markov chains are frequently used to examine intertemporal interaction processes with a random character, where the probabilities only depend on the events in the last period. In the simulation model, the programming models simulate the events and the Markov chain the random interaction. Basically, cooperation of farms can be included in such a simulation model in a manner similar to land transfer (cf. De Swart *et al.*, 1997).

Alternative ways of mixed farming can be included as options in the farm models. Advantages and disadvantages of mixed farming will differ according to the actual farm situation. Farms with the biggest advantages of collaboration will be matched first, followed by farms with the near highest benefits, etc. until the possibilities for profitable matches are depleted. Running this simulation model with and without mixed farming enables its impact on regional structure to be ascertained.

Final comments

Studies of agricultural production, and of mixed farming systems in particular, comprise contributions of various disciplines. The specific contribution of farm economic research is that it can identify the factors determining the possibilities for 'adoption' of mixed farming in practice. If new farming systems are to be adopted, they have to meet various criteria at the same time; see Norton & Mumford (1993). Such systems should not only be technically possible and economically viable, practicable compatibility and social acceptance are just as important. Technical researchers and policy makers should be aware of the importance of such criteria when designing mixed farming systems and developing policies to stimulate their introduction.

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General information

The Workshop on 'Mixed Farming Systems in Europe' is hosted by Agricultural Knowledge Centre (AKC) Flevoland. The Mixed Farming Systems research of Wageningen Agricultural University (WAU) at the Minderhoudhoeve is part of AKC Flevland. Other participants are, among others, the Chirstian Agricultural College (CAH) and the Bio-Dynamic Agricultural School Warmonderhof, both at Dronten.
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