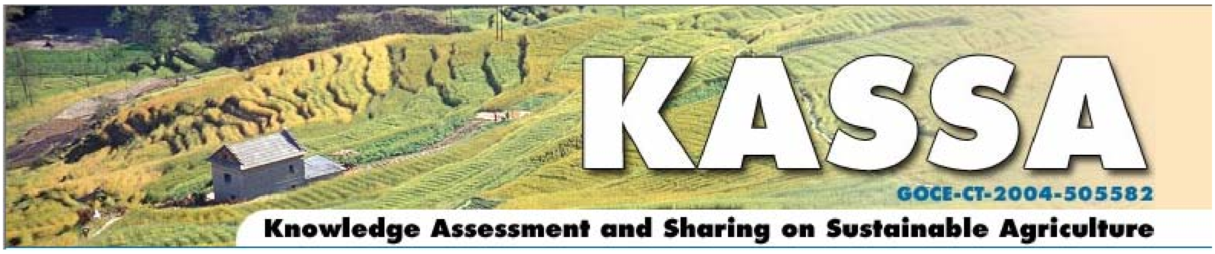

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Organic farming in Denmark

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Abbreviations

AFK	Institute of Local Government Studies
DARCOF	Danish Research Centre for Organic Farming
DMU	National Environmental Research Institute of Denmark
DTU	Danish Technical University
KVL	Royal Veterinary and Agricultural University of Denmark
OF	Organic farming
Risø	Risø National Laboratory
UC	University of Copenhagen

BRIEF INTRODUCTION TO THE DANISH AGRICULTURE AND ASSOCIATED ENVIRONMENTAL CONCERNS

Basics

Denmark has a population of approximately 5.4 million inhabitants and comprises a land surface area of about 42,000 km^2. Natural resources include petroleum, natural gas, fish, salt, limestone, chalk, stone, gravel and sand. Approximately 54% of land area in Denmark is arable, 0.4% of this stands under permanent crops. Agriculture provides about 2% of GDP and employs 4% of the population. The main agricultural products include barley, wheat, potatoes, sugar beets, pork, dairy products and 'fish'.

Jutland is the peninsula to the west, while the central-eastern island is Zealand, housing the capital, Copenhagen, and about a third of Danish population. Jutland is generally considered the most 'rural' part of Denmark, as a higher percent of the population is employed in the primary sector there than elsewhere in Denmark.

Pedo-ecological and climatic conditions

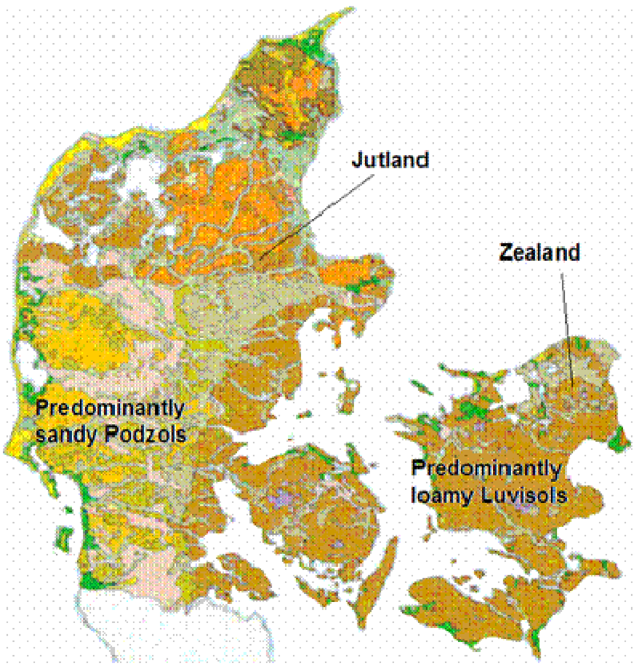

Fig. A. Distribution of some major soil types in Denmark. Sandy Podzols dominate agricultural land in south-western Jutland (indicated by ■, ■, ■), while loamy or clayey Luvisols (■) are common over much of the rest of agricultural land in Jutland and the isles.

Much of Denmark's landscape is flat or gently undulating, the lowest point being 7 m below sea level, while the highest point is 173 m above sea level. Marshes and sandy 'young moraine' Podzols (FAO classification) on low, flat topography dominate most of south-western Jutland, while more fertile, humic loamy or clayey Luvisols on an undulating topography are common over much of the rest of Jutland and the Danish isles (Fig. A).

Denmark's maritime climate, apart from occasional cold winters, rarely suffers extremes of weather and does not vary much throughout the country. Precipitation occurs all the year round, but summer and autumn are the wettest seasons. Annual precipitation ranges from >900 mm in some parts of Western Seaboard to approximately 500 mm over the main island belt. The average duration of winter snow cover is about thirty days but in some winters there may be little snow. Daily sunshine hours range from between one and two in winter to about eight in summer. July is the warmest month with a mean temperature over 17.5 ºC in southeast and just below 16 ºC in the northwest of Jutland. January is the coldest month in Denmark, but the mean temperature of 0 ºC is more even throughout the country due to the warming effect from the surrounding sea.

The diversity of pedological/uniformity of climatic conditions across Denmark means that all production systems are represented throughout the country, although dairy farms are more prevalent in southern Jutland, while crop farms are most common in the east. Jutland has a higher percentage of population employed in the primary sector compared to the Danish average.

The Danish public and the farming community's views on agricultural pollution

As a result of specialization and intensification of agricultural production over the past few decades, there has been a substantial increase in the use of fertilisers and pesticides. This has led to serious environmental pollution problems, the main problems being related to nitrates, pesticides and phosphates in inland aquatic environments and marine waters such as the Skagerrak, the Kattegat and the Baltic Sea (Oldrup & Just 2000). The seriousness of the nitrate problem in Denmark is highlighted by the fact that the whole of Denmark has been identified as vulnerable to agricultural nitrate pollution in the context of the European Nitrate Directive (Oldrup & Just 2000).

Public awareness of the problems about nitrate and phosphorous leaching and contamination of water sources was raised by scientific reports in the early 1980's, but policies to abate such form of pollution were not formulated until 1985, involving a complex system of regulations of when what could be used where. A pesticide action plan was introduced in 1987, but pollution from pesticides did not really become a public issue until more evidence about residues in drinking water became public in the 1990's. Following this, pesticide regulations have been rather restrictive in the latter half of the decade, imposed mainly in form of taxes on pesticides.

The first reaction of farmers' organisations towards environmental concerns was a denial of any connection between agricultural practices and nitrate pollution. But gradually this attitude has changed, farmers' organisations now taking part more constructively in the policy process. Their attitude was and is still that pollution problems, if any, should be solved mainly through voluntary measures. The Ministry of Agriculture shares this position, which especially in the 1980's lead to many controversies between the ministries of agriculture and environment, the latter recommending economic measures against agricultural pollution.

Organic farming, integrated production (IP) and reduced tillage systems

As a response to the problems associated with intensive and specialised agriculture, several production systems have been promoted as a means of balancing agricultural production with sound environmental stewardship.

Organic agriculture has been supported through a set of subsidies, both for conversion and for production since 1988. Organic agriculture advisory services are integrated within conventional agricultural advisory services.

Integrated Production (IP) is a proposal for good farming practices without clear and controllable rules and guidelines. In Denmark it was put forward by researchers and adopted by Danish farmers' organizations in 1996. No particular financial support exists for farmers following these practices.

Reduced tillage: Currently no statistical data exists for reduced tillage systems in Denmark, and apart from specialist advisors within the Danish Agricultural Advisory Centre, no particular external or financial incentives have been launched to help promote this system. The generally flat topography and low rainfall intensities of Denmark by and large make it of less immediate value than in other areas without such features.

1. CONTEXT AND DIMENSIONS OF DANISH ORGANIC AGRICULTURE

In 2003, 3510 organic holdings were registered in Denmark, which represented 7.2% of the total number of Danish agricultural holdings and covered about 147,000[1] ha or 5.5% of agricultural land (Danmarks Statistik 2004). The average farm size of organic farms stood at 48 ha compared to 53 ha for the average of all Danish farms. Eleven percent of organic farms was smaller than 5 ha, while 15% were larger than 100 ha. Organic crop production, including horticultural crops, contributed **8.4% of total Danish crop production**, while **organic cattle (dairy and meat) compromised 7.7%**, **mixed livestock-crop activities 5.7%** and other **organic livestock 1.6%** of their respective total annual output in Denmark. Ten percent of milk and 14% of all eggs in Denmark in 2003 were produced organically.

Table 1

Authorised land uses under organic agriculture in Denmark, 2003. (Source: Danmarks Statistik 2004)

Land use	Organic ha	% organic of total	% of organic
Grass & green fodder	84000	13	57
Cereals	46000	3	31
Grain legumes	6500	21	4
Set aside land	4300	2	3
Seeds for sowing	3000	3	2
Horticultural products	1300	7	<1
Root crops	1200	1	<1
Seeds for industrial use	1200	1	<1
Other crops	440	17	<1
TOTAL	147400	6	100

Table 2

Organic Livestock Units (LU) in Denmark, 2003. (Source: Danmarks Statistik 2004)

	Organic LU	% organic of total	% of organic
Cattle	106000	11	88
Pig	6000	<1	5
Poultry	5000	6	4
Sheep & horses	3000	3	3
TOTAL	120000	5	100

1.1. Break-up of organic land uses

In terms of acreage, the large majority (45-50%) of organic production falls under plant husbandry, one fifth under dairy, 10-15% under mixed crop-livestock production, 15-20% under “small” and about 5% under “other production”, a ratio that varies somewhat between regions of Denmark but is not significantly different from that of conventional agriculture (Frederiksen & Langer 2004). In terms of holdings, 57% of organic farms in Denmark grow grass or green fodder, 31% cereals, 4% pulses, 3% contain set-aside land, 2% seed for sowing, and less than 1% include horticultural products, root crops, seed for industrial use or other crops (Table 1).

The crop choice on organic farms differs from national averages. Typically, grass and green fodder areas double after conversion, while cereal areas decrease significantly, reflecting the importance of organic ruminant and the lack of fertilizer and pesticides for cereal cultivation. Instead, organic farmers grow more N-fixing and undersown or catch crops, as well as vegetables on a proportionally larger area. The major organic cereals include winter and spring varieties of oats, rye, barley, wheat and triticale, while the predominant organic vegetables include carrots and onions.

Livestock densities are lower on organic farms than Danish averages. Livestock units (LU) are also distributed differently (Table 2). Cattle and pig LU, for example, account for 88% and 5% of organic LU, whereas they amount to 40% or 48% on a Danish average. Organic sheep, horse and poultry, on the other hand, are grown in similar percentages to those on a national scale. Forty-two percent of organic cattle compromise dairy or suckler cows, while egg production dominates the organic poultry sector.

[1] Discrepancies between the actual organic hectarage exist as the Plantedirektoratet (under Ministry of Food, Agriculture & Fisheries) counts land in the process of conversion, while Danmarks Statistik apparently only tallies fully certified and registered plots.

1.2. Regional concentration and specialisation of Danish organic agriculture

Figure 1A shows the density of organic farms per area-unit of agricultural land, which as a national average amounts to 14 farms per 100 km^2. A certain regional concentration of organic farms exists, especially in Southern Jutland (peninsular Denmark), but also in the counties surrounding the two largest urban areas of Denmark. Regional specialisation (Fig. 1B) generally characterises the Danish organic farming sector, with areas supporting a high density of livestock enterprises generally being confined to Jutland while organic crop cultivation dominates eastern Denmark. In terms of distinct characteristics of organic compared to conventional farms, Langer (2001), using data from nearly 450 Danish farms prior to and planned after conversion, found that the characteristic regional pattern of farm types remained similar regardless if organic or conventional.

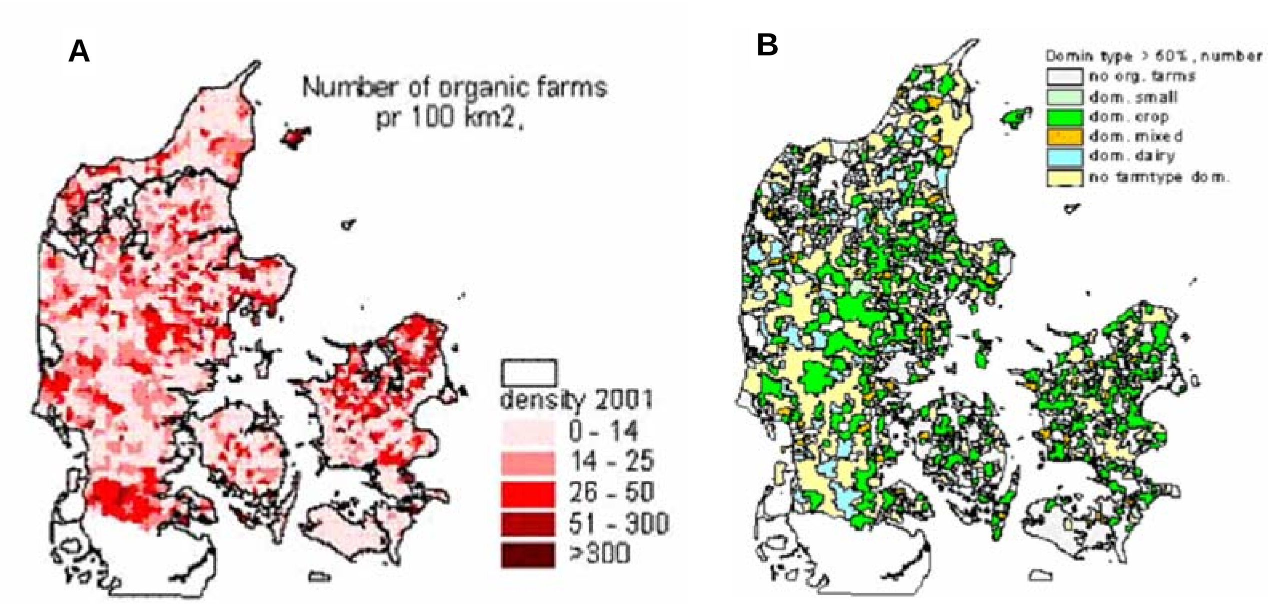

Fig. 1. Maps of Danish OF. **A.** Density of organic farms in Denmark in 2001 calculated as number of organic farms per 100 km^2 of agricultural land. **B.** Dominating farm type within local areas (parish level), based on a classification of areas where one farm type constitutes more than 50% of total number of organic farms. (Both from Frederiksen & Langer 2004).

Although one of the objectives of the Danish Organic Farming Association is to promote a diverse production - with harmony between the crop and the livestock production - the majority of Danish organic farms are specialised, and only a minor share of organic farms compromises mixed enterprises (without dominance of one production branch). However, a survey conducted among 10% of all Danish organic farmers in 2001 showed that, despite regional specialisation, 31% of interviewed farmers interchanged fodder and manure with other farmers within their neighbourhood, therefore indicating that between-farm diversity existed and that if farm borders *per se* are not used as the strict delineation of the system, there is a certain degree of heterogeneity (Frederiksen and Langer 2004).

1.3. The dynamics, driving forces and extension of Danish organic agriculture

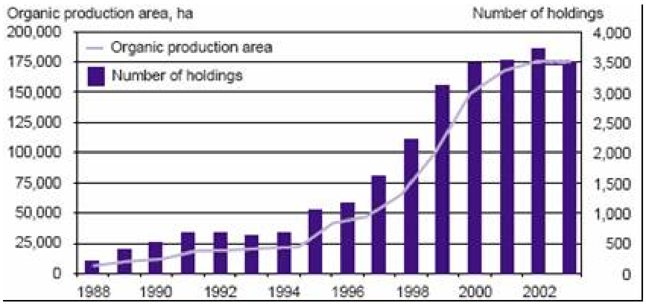

Fig. 2. Development in the number of holdings and area under or in the process of converting to organic agriculture in Denmark (From Plantedirektoratet 2004)

Since the mid-1980'ies Danish agriculture has been subject to a growing conversion into organic farming (Fig. 2). The number of organic holdings and the land has steadily risen, peaking in 2002 with 3714 organic households or 7.3% of total agricultural land under organic management. This trend, however, has been reversed over the past two years. In 2003 there were 204 less registered organic holdings than in 2002, while Kaltoft & Risgaard (2004) furthermore observed that about 500 organic farmers had left the organic sector in 2004, with an additional significant number of organic farmers at least considering reverting back to conventional farming.

Conversion to organic farming shows a large variation at the county level in Denmark. This is attributed to proximity to urban markets and values, regional specialization of farm types and municipal promotion of organic farming. However, also at the local level there is a substantial variation in the localization of organic farms, which may be related to negative influences of social barriers and positive influences of fiery souls among producers and advisors (Oldrup 1999; Frederiksen & Langer 2004; Kaltoft & Risgaard 2004). Studies have shown that in southern Jutland, with its high organic farm density, several initial supporting aspects for conversion have existed, both in terms of a project promoting organic farming in a number of municipalities, as well as capacity building at regional level in terms of using structural funds (Frederiksen & Langer 2004). In Denmark, subsidies for organic farming are granted both for certification (conversion support) and for production, and all farmers who fulfil the criteria can obtain them. However, while certification and subsidies for organic production are horizontal drivers, structural development funds may function as a regional localisation parameter. Only some areas are eligible for funding of the latter, and such funds have, for example, been granted for the renewal of stables in relation to conversion, thus favouring regions with dairy production, while, on top of this, prices on organic milk in the mid-1990s pulled in the same direction (Frederiksen & Langer 2004). In their interviews with 10% of all registered organic farmers, Kaltoft & Risgaard (2004) found that, while general subsidies were not considered important, a number of farmers had probably entered organic farming solely in order to obtain structural funds, and after their 5-year mandatory commitment period to organic farming had expired, reverted to conventional farming.

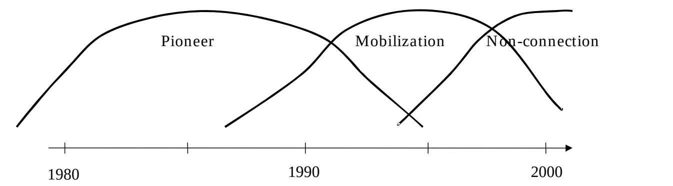

Fig. 3. Schematic illustration of the three phases of the conversion to organic farming and organic network building in Denmark (From Noe 2003b)

Studies by Michelsen (2001) and Noe (2003a,b) on reversion of organic farmers to conventional farming further point to different phases of conversion dominated by marked differences in attitudes toward organic and conventional farming. The pioneer phase of organic conversion in the 80ies was mainly dominated by actors that did not belong to the mainstreams of agriculture, frequently part-time rather than full-time farmers, who often held strong negative attitudes toward conventional farming and rationalised their choice of conversion through environmental concerns. Later, what Noe (2003b) terms the enrolment or mobilisation phase occurred, and local conventional actors were mobilised into the organic network (Fig. 3). Subsequently the non-connection phase followed, where farmers converting to the organic mode of farming no longer necessarily were enrolled in the organic network and where the conventional agricultural networks had adopted organic farming as a concept into the conventional network strategies (Fig. 3). Noe (2003a) found that, while full-time farmers converted before 1993, like their part-time colleagues, held strong negative attitudes toward conventional farming, full-time farmers converted in 1997 did not hold these same critical viewpoints and mainly rationalised their choice of conversion from an economic rather than environmental concern position. These latter, for example, also gave no priority to the idea of better, healthier products being produced through organic farming, and very few among them actually ever purchased organic produce for themselves (Kaltoft & Risgaard 2004).

1.4. Sale of organic produce in Denmark

Denmark has the largest per capita consumption of organic products within Europe, and nearly all consumers in Denmark recognise the organic label (Weir & Andersen 2003). Organic milk and rolled oats which account for about 25% and 27% of their market share are the most successful organic products, followed by eggs (17%), carrots (13%), wheat flour (8%), fresh pasta (8%), cultured milk products (5%), rye bread (5%), butter/mixed products (4%), coffee (4%), potatoes (3%), feta cheese (2%), beef (<1%), frozen vegetables (<1%) and pork (<0.5%). Although organic products were initially sold mainly through consumer subscription arrangements or in farm shops, etc., most are now sold in supermarkets (Table 3). In percentage terms, the export of organic products is much lower than the export of other agricultural products.

Table 3

Source of some organic food purchases in Denmark in percent (From Oldrup & Just 2000)

	Cereals	Vegetables	Milk
Direct sales to consumer	<2	10-20	0
Specialised organic food shops	0	<2	<2
Specialised shops (bakers and butchers)	5	0	0
General stores incl. super/hypermarkets	90-95	80-90	98

2. CONDITIONS OF OBTAINING RESULTS

2.1. Research partners

Many research groups involved with a broad range of research concerning aspects of Danish organic agriculture exist within various Danish institutions and centres. Organic agricultural research is co-ordinated primarily by the **Danish Research Centre for Organic Farming (DARCOF)**, a so-called "centre without walls", established in 1995, where actual research is performed in interdisciplinary collaboration between 15 participating institutions or research groups.

The main research protagonists in terms of agricultural/agronomic research into organic farming (OF) in Denmark are found within:

- the **Department of Agricultural Science** of the **Royal Veterinary and Agricultural University of Denmark (KVL)** → *based in Copenhagen, with an experimental farm outside Copenhagen (Taastrup).*
- the **Danish Institute of Agricultural Sciences (DIAS)** under the Ministry of Food, Agriculture and Fisheries → *various research stations and experimental locations throughout Denmark,*
- **Risø National Laboratory** under the Ministry of Science, Technology and Innovation → *based close to Roskilde*.

In terms of broader biophysical, but also socio-economic and politico-cultural research (e.g. OF in the Danish agricultural landscape, OF and nature quality, organic food quality, etc.), many institutions and organisations play varying roles. These include:

- the National Environmental Research Institute of Denmark (DMU) under the Ministry of Environment,
- other departments at KVL,
- the Institute of Local Government Studies (AFK),
- institutes or departments of other Danish universities (e.g. the Institute of Geography, University of Copenhagen, or the Institute of Environment and Resources, Danish Technical University). In 2000, universities other than KVL contributed 1% to organic agricultural research (Oldrup & Just, 2000).

2.2. Main field experiment sites in Denmark

A number of organic field experimental sites were established in 1996 as part of the joint effort on Danish organic farming research coordinated by DARCOF. These are described in www.okoforsk.dk/projekt/iv1/ans.pdf and the following text in this section will draw on this document unless otherwise stated. The main locations of field experimental sites include Askov (DIAS), Flakkebjerg (Risø), Foulum (DIAS), Jyndevad (DIAS), KVL-Taastrup, Årslev (DIAS), the long-term crop rotation experiments at Jyndevad, Foulum, Flakkebjerg and Holeby, as well as the Organic Farming Research Station in Rugballegård. The idea is that these experimental sites cover all major organic farming practices, soil types and climatic conditions in Denmark (Fig 4). Each course of a rotation is represented with an area of about 1 ha, which allows for factorial field experiments within each field while at the same time maintaining a fixed rotation. The effects of the rotations are monitored through measurements in references areas not subjected to experimentation, and measurements include general yields and nutrient balances (NPK) at all sites, as well as weeds, diseases and pests at some of the sites.

Fig. 4. Map of locations of organic farming experimental sites in Denmark (From www.okoforsk.dk/projekt/iv1/ans.pdf)

Location	Soil texture	Type/title of trial/experiment	Run by
Askov	Loamy sand	• Long-Term Fertilisation Experiment	DIAS
Flakkebjerg	Sandy loam	• Cereal and Seed Crop Rotations	Risø
Foulum	Loamy sand	• Dairy/Crop and Pig/Crop Rotations • Nutrient Cycling Experiment • Grass/Clover Experiment	DIAS
Jyndevad	Sand	• Cattle/Crop Rotation	DIAS
KVL-Taastrup	Sandy loam	• Dairy/Crop Rotation • Combined Food and Energy Production	KVL
Rugballegård	Loamy sand	• The Organic Experimental Station	DIAS
Årslev	Sandy loam	• Vegetable Crop Rotation • Fruit and Berries Experimental Area	DIAS
Jyndevad, Foulum, Flakkebjerg, Holeby	Sand – loam	• Crop Rotation Experiment	DIAS

N.B. Biophysical characteristics of all these sites are given in greater detail in the KASSA database

2.2.1. Askov

The Askov experimental area represents parts of a long-term fertilisation trial with animal manure and mineral fertilizers (established 1894), which has been converted to organic farming in 1996. The experimental treatments include different rates and types of application of animal manure (3 levels of cattle slurry, 4 levels of solid manure and unmanured plots), while the measured outputs include yields and nutrient balances, with soil samples being taken every four years.

2.2.2. Flakkebjerg

The experimental area at Flakkebjerg consists of two crop rotations, the first being converted to organic in 1996, and a second in 1999/2000 due to the large demand for experimental areas for organic farming. Fields are supplied with conventionally produced slurry at rates corresponding to 25% of the demand for nitrogen (N) in the rotations. The main experiments conducted within this set-up deal with cereal production and weed control.

2.2.3. Foulum

There are two organic experimental areas at Foulum, a dairy/crop rotation and a cereal-dominated pig/crop rotation. Nutrient balances in the organic dairy rotation have been recorded since 1987 and it is now being used for a nutrient cycling experiment. Up until 1998, two levels of cattle slurry corresponding to 0.9 and 1.4 LU per ha and two different manure management systems, slurry and deep litter/slurry were applied to this experiment. However, as these treatments only resulted in very small differences in terms of yields, N balances and nitrate leaching, the levels of manure have been modified to correspond to 0.7 and 1.4 LU per ha and applied in form of either pure slurry or pure deep litter rather than mixed applications. The pig/crop rotation has mainly been used for experiments with potatoes. Another experimental area at Foulum is being used for research on the effect of grass/clover management on following crops and nitrate leaching. This experimental site has been used to research different levels of cattle protein-intake and milk yield, as well as grass growth under grazed conditions, the effect of grass/clover pasture history, age and composition on cereal crop yield and nitrate leaching after incorporation of the clover/grass, and on nitrate leaching during the grass phase. Both the 'Nutrient Cycling Experiment' and the 'Grass/Clover Experiment' function as both individual experiments and as experimental areas for other projects.

2.2.4. Jyndevad

The crop rotation on sandy soils at Jyndevad consists of grass/clover and cereals in a seven-course rotation that was initiated in 1996. Each of the seven fields is additionally subdivided into three blocks each receiving five different manure treatments very similar to those applied within the ‘Nutrient Cycling Experiment’ at Foulum (i.e. a unmanured control and the equivalent of 0.8 and 1.4 LU per ha applied either as slurry or deep litter). The Jyndevad fields have primarily been used for grain quality trials of oats and for potato production.

2.2.5. KVL-Taastrup

Two experimental areas are used for organic farming research at the KVL university farms. The organic crop rotation is mainly used for studies on effects of soil tillage and weed control, having been managed organically since the establishment in 1988, while the ‘Combined Food and Energy Production’ experiment comprises fields of different lengths, on which crops are rotated and which are separated by hedges for energy production. The principal idea behind this set-up is to grow short rotation coppice in strips between food crops to get an energy crop in addition to the food crops, the goal being the generation of at least as much non-fossil renewable energy from fast-growing hedge biomass as is consumed in fossil-energy in those parts of the system devoted to food and fodder production. The hedges regrow naturally after coppicing every 4-5 years, and the whole set-up is 150 m wide, composed of four 50, 100, 150 and 200 m length blocks separated by shelter-belts of either willow, hazel and alder, thereby accommodating studies on energy balances, biodiversity, shelter effects and N and carbon balances.

2.2.6. Rugballegaard

The Rugballegaard organic experimental station is the only facility where full scale organic production (livestock grazing within different crop rotation systems) can be registered and is mainly used for experiments with cattle and pigs and to study crops-livestock interactions. Rugballegaard has fields of different sizes, although all are larger than 3 ha. In 1996, three crop rotations representing different model farming systems (dairy, pig and combined dairy and pig) were established on 140 ha. The crop and livestock yield are continuously recorded and nutrient balances calculated at field and farm levels. Measurements also generally include weed and diseases incidence and are taken either in reference areas or at field and system level.

2.2.7. Årslev

The Årslev set-up includes both an experimental area for organic vegetable crop rotation and perennial fruit crops and berries, where soil nutrient status and occurrence of weeds, pests and diseases are monitored. The organic vegetable crop rotation is a six-course rotation, where three of the fields are sown to vegetables and three to grass/clover or cereals. The N supply is solely based on residual crop N, green manures and catch crops. The experimental area under fruits and berries comprises trials on organic apples, black currant and strawberries, as well as unsprayed cherry trees are maintained for studies in these crops.

2.2.8. The ‘Crop Rotation Experiment’ at Jyndevad, Foulum, Flakkebjerg and Holeby

Similarly to the nutrient cycling and grass/clover experiments conducted at Foulum, the ‘Crop Rotation Experiment’ functions both as an individual experiment and as experimental set-up for other projects. The trial itself focuses on different aspects of crop rotations for organic cereal production in a factorial design (three factors with two replicates) and outputs include yield, nutrient balance and weed assessment, as well as nitrate and potassium (K) leaching measurements using porous ceramic cups in selected plots. The factors comprise (1) fraction of grass-clover and grain legumes – pea and lupin - in the rotation, (2) catch crop (without or with catch crop – clover, ryegrass or clover-ryegrass mixture - or bi-cropped clover), and (3) fertiliser (without or with animal manure applied as slurry), and each is conducted at four locations

(Jyndevad, Foulum, Flakkebjerg and Holeby), each location representing a distinct edaphic and climatic region of Denmark (Fig. 4). Jyndebad, in southern Jutland has sandy soils typical of the region, while Foulum has loamy sands, Flakkebjerg sandy loam and Holeby loam soils. There are 64 experimental plots at both Jyndevad and Foulum, 72 at Flakkebjerg and 12 at Holeby. Specific details of these plots are provided in Djurhuus & Olesen (2000), while Olesen et al. (2000) discuss the main design requirements. All fields in all rotations are represented each year, with the first course of the rotation completed in 2000, and the second course adjusted slightly to optimise each crop rotation with respect to nutrient management and opportunities for weed control.

2.3 Surveys of organic farmers

Fig. 5. Map of locations of organic farming surveys in Denmark

The research into the changing dynamics of OF and its driving forces, as well as data on general characteristics and regional concentrations of organic farms have been elucidated through surveys among organic farmers selected to represent major landscape and farm types, as well as farmers in the process of conversion or reversion (presented in Sections 1.2 and 1.3). As an example, one such project has selected 10 study areas where organic farming is more common than in the rest of the country (Fig 5). There are about 30 organic farms in each area and the size of the area reflects a combination of both size and closeness of the organic farms. These surveys began in 1997, have been repeated several times and aimed to include more than 10% of all Danish organic farms, including both 'old' (before 1994) and ’new’ organic farms.

3. ANALYSIS AND SYNTHESIS OF INFORMATION COLLECTED ON ORGANIC FARMING

Research into issues one way or another related to Danish organic agriculture is very broad and covers both more conventional topics such as the agronomic impact of organic crop rotations and cropping patterns or conversion and reversion processes of organic farmers, as well as less conventional topics such as the use of weeding robots, the working environment on organic farms, nose-ringing swine, recycling urban household waste and sewage into agriculture or the degradation of transgenic DNA from GMO plant material during composting, etc. Currently, well over 500 articles, posters, oral presentations somehow concerning some component of organic agricultural research are registered on Danish organic agriculture databases available on the internet. Probably the most exhaustive of these databases is http://www.orgprints.org, but the DARCOF II research website http://www.darcof.dk/research/darcofii/index.html also contains a comprehensive amount of relevant material and is probably slightly easier to navigate. This synthesis will not attempt to cover all topics, but limit itself to those most immediately relevant in terms of agricultural production, especially crop production, as well as the position of organic agriculture vis-à-vis society and the environment.

3.1. Plant production

Combined livestock and crop farms that rely on astute crop rotations integrating both grass-clover pastures and arable crops are often reasonably robust in relation to many weed, pest and disease problems (Dubois et al. 1998). Such rotations, however, receive large N inputs from N_2-fixation by the grass-clover pastures, which may bear an associated risk of causing environmental problems through nitrate leaching if not managed appropriately (Høgh-Jensen & Schjørring, 1994; Jensen & Hauggaard-Nielsen 2003). Farms solely growing arable crops and vegetables, on the other hand, may suffer from lack of N and be less competitive against annual weeds if a higher proportion of cash crops and smaller share of grass-clover is used. Additionally, due to EU Council Regulations 1804/1999 specifying that from 2005 all feed used in organic animal production must be organically produced there is a requirement for increased production of protein and cereal crops in Danish OF systems to meet the increasing demand for the feeding of monogastric animals (i.e. pigs and poultry). These issues will be dealt with in this section, drawing largely on the results of the various Danish organic trials and experiments briefly described in the previous section (Section 2.2)

3.1.1. Nutrient sufficiency, excess and leaching in organic cropping systems

- The major challenges include adequate nutrients supply to crops, especially on stockless farms, while at the same time avoiding excessive nutrient leaching
- Incorporating grass-clover ley or green manure/catch crop components into the crop rotations alleviate some of these problems and increase successive cereal yields. Catch/cover crops are especially important on sandy soils, where they can decrease N leaching by up to 40%
- Allowing crops to grow in the field until late autumn leaves less N in the soil, which reduces risk of leaching loss. If not possible to establish an autumn soil cover, deep-rooted crops in the next season can recover some of the N leached to greater depths
- If economically important yields are cumulated over a number of years, rotations without a green manure crop produce highest total grain yields → yield benefits induced by the green manure cannot compensate for yield reduction from leaving part of rotation out of commercial production
- Furthermore, although rotational yields were affected by rotation, manure and catch crop factors in trials across Denmark, the largest effects on both DM and N yields were induced by differences

between experimental sites (differences in soils, climate and cropping history)

Crop rotations, catch and intercropping for grain and animal fodder/pasture production: The possibilities for increasing grain yields and reducing N leaching losses in organic cereal production through manipulation of crop rotation design and catch cropping patterns, as well as producing protein-rich animal feed and crops of sufficient market value through intercropping grain legumes with cereals, have been investigated and some results reported from the field experiments on different soil types across Denmark from 1996 to present (described in Section 2.2). Especially pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.) and blue lupin (*Lupinus angustifolius*) have been trialled together with barley (*Hordeum vulgare* L.) and oilseed rape (*Brassica napus* L.) in terms of cereal/grain legume intercrops, as these species in particular are well-suited to Danish climatic conditions, while undersown ryegrass (*Lolium perenne*) or grass-clover (*L. perenne* / *Trifolium repens* and *T. pratense*) leys have commonly been used as catch or cover crops/green manures for grain and animal fodder production systems.

Two of the three four-course rotations used in the 'Crop Rotation Experiment' at Jyndevad, Foulum, Flakkebjerg and Holeby (refer to Section 2.2.8) had one year of grass-clover as a green manure/catch crop, followed by either spring or winter wheat (*Triticum aestivum*). The grass-clover was replaced by winter cereals in the third rotation, and animal manure was applied as slurry in rates corresponding to about 40% of the N demand of the cereals. Rotational grain yields of the cereal and grain legume crops were calculated by summing yields for each plot over the four years in the rotation. Olesen et al. (2003) noted that although rotational yields were affected by all experimental factors (rotation, manure and catch crop), the largest effects on both dry matter (DM) and N yields were induced by differences between sites (differences in soils, climate and cropping history), rather than the actual rotations. However, within sites, rotations without a green manure crop produced the greatest total (cumulative) grain yields, dry matter and N yields being about 10% higher compared to rotations with a grass-clover ley in one year of four (Olesen 2003), even though the grass-clover ley positively enhanced cereal grain yields and N uptake in the Foulum loamy sand (Vinther et al. 2003) and cereal as well as soil microbial parameters the Flakkebjerg sandy loam (Olesen et al. submitted) during the 2001 season: these yield benefits simply cannot compensate for the yield reduction resulting from leaving 25% of the rotation out of production over the four-year period. Possibly, however, the currently only small yield benefits from the use of catch crops may become more significant over time as fertility builds up in the system with catch crops and more nitrate potentially leached or 'caught' and recycled.

Turning to the intercrop component of the trials, Andersen et al. (2005) studied the interspecific complementary and competitive interactions between pea, barley and oilseed rape grown as dual and tri-component intercrops on a sandy loam and observed that all intercrops displayed land equivalent ratio values close to or exceeding unity, indicating that there was indeed complementary use of growth resources, although the benefits achieved from the association of a legume and nonlegume in terms of N_2 fixed were greatest when pea was grown in association with rape as opposed to barley. This possibly indicates that the benefits achieved from the association of a legume and nonlegume are partly lost if the nonlegume is too strong a competitor. Knudsen et al. (submitted) also found that lupin-barley intercrops displayed less intercropping advantages (i.e. increased the barley grain N concentration and N derived from N_2 fixation) than did intercropped faba bean and pea, but that lupin generally constituted a more stable yield proportion of the combined intercrop yield over locations. Knudsen et al. (submitted) further mention that the later maturity of faba bean compared to barley caused problems at harvest. Results for a range of other factors pertaining to the intercropping component of the various experiments/trials are reported in Haugaard-Nielsen et al. (2001a,b,c; 2003a,b; 2005a,b), Jensen et al. (2001), Joernsgaard et al. (2003).

In terms of specific nitrate leaching after grass-clover pastures, both Olesen et al. (2004a) and Eriksen et al. (2004a) found that over 3 years (1998-2001) in the 'Crop Rotation Experiment' this did not differ significantly between the rotations studied, as a change in leaching following the grass-clover was compensated by a reverse effect in the grain crops. At crop rotation level, the inclusion of cover crops reduced N leaching by 23 to 38% with the highest reduction on the coarse sandy soil (Olesen et al. 2004a) and the replacement of the winter wheat crop used in the earlier experimental period (1994-97) by spring oats with catch crops in both the preceding and succeeding winters reduced nitrate leaching compared to the earlier rotation (Eriksen et al. 2004a). Potassium (K) leaching decreased from 42 kg per ha in 1998/99 to 21 kg per ha in 2000/01 as an average of a crop rotation (spring barley, grass-clover, winter wheat and pea/barley) with manure application and without catch crops, but over the same period, spring exchangeable K decreased from 5.0 to 3.0 mg K 100 g^{-1} soil (0-20 cm) (Askegaard et al. 2003). Sulphate (S) leaching decreased significantly during the 3 years, and the concentration of S in drainage water was lowered 5.5 times in the third year. Similarly, the S-content of the crops decreased significantly over the years, reflecting lower soil S availability (Eriksen et al. 2002). At two experimental sites with either a sandy loam and a coarse sand, catch crops showed huge differences in their ability to sequester S. The best catch crops (legumes on sandy loam) sequestered 10-12 kg S per ha while the poorest (ryegrass and sorrel on coarse sand) sequestered less than 3 kg S per ha (Eriksen et al. 2005). The S mineralization rates were highest for crucifers (57-85% of total S added) and lowest for legumes (up to 46% of total S added).

Although an increasing amount of stockless organic farms are emerging, an ideal organic farm should include some livestock component, and most of the DARCOF organic trials incorporated various levels and types of animal manure (both conventional and organic) into the rotations. Applications of 50 kg NH_4-N per ha in manure (slurry) increased barley grain DM yield by 1.0 to 1.3 Mg DM per ha, whereas the use of cover crops (primarily perennial ryegrass) increased grain DM yield by 0.4 to 0.7 Mg DM per ha, the smallest effect occurring on the sandy loam soil and the highest effect on the coarse sandy soil (Olesen et al. submitted). The actual N use efficiency of NH_4-N in the applied manure varied from 25 to 39% corresponding to N use efficiencies obtained with mineral N fertilisers. Using the same experimental set-up, Eriksen et al. (2004a) observed that increasing the livestock density from 0.7 and 1.4 livestock units per ha, which increased manure application by approximately 60 kg of total N per ha, increased crop yields by 7 and 9% on average for straw-based farm yard manure (FYM) and slurry, respectively, yields being 3-5% lower where FYM was used rather than slurry.

Vegetable production: After six years of organic vegetable production using catch crops, green manure crops and crop sequences aimed at a high utilisation of precrop effects, results from Årslev trials indicate that it is possible to maintain good crop yields even without livestock manure, and hence that farming with less domestic livestock is potentially possible (Thorup-Kristiansen 2002; Thorup-Kristiansen 2004). Yields of leek and carrot were as high as in conventional cropping, while yields of onion, cabbage, green peas, and the two spring barley crops included in the crop rotation were lower than conventional yields, but still good by organic standards. Though many different types of crop cover have been involved in these trials, ranging from full year green manures to short-term catch crops and even white cabbage stubble allowed to continue growth after harvest, all these crops had a similar effect on N dynamics in the field, although the amount of N mineralized obviously varied depending of the type of crop cover. Allowing crops to grow in the field until late autumn means that much less N is left in the soil, and the risk of leaching loss is strongly reduced. In the subsequent spring, mineralization of N from the crop residues leads to increased N availability for the succeeding crop. The results also show that when it is not possible to establish an autumn soil cover, it is important to grow deep-rooted crops in the next year in order to recover some of the N leached to greater soil depths. Finally, undersowing legumes into spring cereals has proven an attractive method, allowing both a grain cash crop and an effective green manure to be grown within the same year. In summary, the Årslev vegetable crop rotations results indicate that limited N supply is not necessarily a major constraint to organic vegetable production, especially as organic farmers additionally have the possibility of adding externally produced organic manures and combing these with the cover crop/green manure strategies tested in these trials.

In terms of organic greenhouse vegetable production, where crops grow in limited beds and can consequently not exploit large soil volume for nutrients, composts are often crucial. In research into optimising greenhouse composts based on plant materials, Dresbøll (2004) found that mineralization processes were altered when postponing adding part of the nutrient rich material for three weeks during composting, hence increasing the nutritional quality of the compost when used as growing medium. In addition, structural studies of compost in Dresbøll's work revealed that differences in actual decomposition rates of different plant materials were not only dependent on lignin content, but more importantly on the anatomical arrangement of tissues.

3.1.2. Modelling N dynamics, crop production and biodiversity in organic crop rotations

- ❖ Dynamic simulation models that integrate analytical studies of system components have been developed to tackle holistic and multi-scale research problems
- ❖ These include DAISY, FASSET and the Food Web Model, which have proven to be satisfactory predictions when compared against empirical data

In order to better handle some of the multiple interactions between levels and scales of OF, as well as realistically grapple with holistic research into such challenges, various dynamic simulation models that integrate analytical studies of system components have been developed. Three deterministic simulation models are currently being used in Danish organic agricultural research, namely DAISY, FASSET and the Food Web Model, and, after certain extensions from the original models have proven to the most degree satisfactory when tested against empirical data from trials for estimating, for example, competition between several plant species for light, water and N in intercrops (Berntsen et al. 2003a), nitrate leaching from an organic dairy crop rotation with different manure types and loads (Berntsen et al. 2003b), the effects of different cutting or grazing treatments of grass-clover leys on rhizodeposition and nitrate leaching (Berntsen et al. 2004) or the simulation of N-mineralization/-immobilisation and of soil microbial biomass N after incorporation of catch crop plant residues (Müller et al. 2003). Future research concerning these models should aim at further expanding them where they do not have sufficient skills, more calibration/validation of the improved models with independent experimental data, and scenario analyses for different crop rotations. This should ideally assist in design of improved crop rotations, as well as helping to evaluate environmental effects of OF systems, such as nitrate leaching, biodiversity and changes in organic matter contents, and generating new hypotheses, which can tighten the focus of future organic research orientation.

3.1.3. Weed management

- ❖ Ploughing is most common weed control in OF, although only few and short-termed post-harvest periods for soil cultivation generally exist
- ❖ Delaying sowing time of winter cereals is effective, but also results in crop yield penalties
- ❖ Ploughless methods to control weeds include using more competitive crop cultivars, as well as other methods to increase the competivity of crops, such as adding slurry close to crop, etc.
- ❖ Further weed management techniques include re- and post emergent interrow hoeing, band steaming, and punch planting in combination with flame weeding → all successful under the right circumstances

In terms of individual weed species, the most problematic weeds in Danish OF are creeping thistle (*Cirsium arvense*) and common couch (*Elymus repens*), both perennial species. Currently, management of the two species is largely unsatisfactory. While more is known about the ecology of *E. repens*, the lack of information on basic aspects of the ecology of *C. arvense* is a major obstacle to managing this species effectively. Additionally, both species are difficult to control by ploughing because organic cropping systems only have few and short-termed post-harvest periods for soil cultivation (Rasmussen et al. 1999). Usually organic farmers prefer to keep the soil covered by plants during most of the post-harvest period to retain nutrients in the upper soil layers and avoid excessive leaching (see Section 3.1.1).

Although Graglia et al. (2004) found that repeated hoeing during the first part of the growing season diminished the regenerative capacity of creeping thistle - results show a linear relationship between the number of hoe passes and the aboveground biomass of the weed in the subsequent years - this strong effect on the biomass of the weed did not result in increased crop yield. A current project is now underway focussing on the ecology of creeping thistle, i.e. its competitive ability against different crops, spread and dispersal of thistle patches, and impact of stem and root cutting on its regenerative capacity, in the hope that this research will shed more light on appropriate control or management strategies (Fogelfors et al. 2003). In terms of common couch, an integrated control strategy, combining rhizome disintegration by soil cultivation in the post-harvest period, with later catch crop growing to suppress shoot growth and recover some leached N, is being studied on a sandy soil and results are expected to add new angles to the management of this problematic weed.

In terms of general weed control, Rasmussen et al. (1999) discusses the early preliminary results of weeds within the 'Crop Rotation Experiment' across the four locations and soil types in Denmark. Here, weeds in cereals and pulses without undersown catch crops were controlled by weed harrowing with spring tine weeders. On the lighter soil types, where the weed infestation was worst, the wheat was sown at double normal row distance and hoed mechanically, as this facilitates hoeing between the rows, especially in winter cereals, where it is often difficult to achieve good post-emergence weed harrowing without damaging the crop (Rasmussen et al. 2000; Cirujeda et al. 2003). Large perennial weed plants (i.e. creeping thistle and *Artemisia vulgaris*) were removed by hand weeding, while common couch was controlled by repeated stubble cultivation after harvest. The sugar beets were kept weed-free by a combination of pre-emergence flaming, mechanical and manual hoeing and hand weeding of large weeds. In the first two years of the experiment, there were no differences in weed flora (species, numbers and biomass) within sites pertaining to crop rotation, but a tendency towards lower weed infestation in cereals without catch crops, where weed harrowing or hoeing had been performed became evident. There was generally a larger weed biomass in the winter wheat compared with the other crops, and there were more weeds (numbers and biomass) in the fertilised plots, although crop biomass was also largest in these plots. Common couch was found in 40-50% of the winter wheat plots on three locations in 1998, but not in as high a frequency in the other crops. Creeping thistle occurred at all cereal crops in 1998, but after harvest it had disappeared from nearly all of the plots with catch crop, but only from very few of the plots without catch crops. However, after only one year of observation, Rasmussen et al. (1999) also admit that it was still too early to draw any definite conclusions about the effect of the crop rotations on the weed flora, although the catch crops certainly seemed to reduce the occurrence of creeping thistle in the cereals, but on the turn side, made mechanical control of other weeds more difficult (Rasmussen et al. 1999). In order to circumnavigate this problem, however, Rasmussen et al. (2000) propose a technique where the underseed is placed in the same row as the crop plants, thereby making it possible to carry out mechanical weed control with little loss of yield and good establishment of the ley or catch crop.

Under the guise of reducing incidences of bare soil and soil disturbance (i.e. reducing ploughing), Melander et al. (2004) report results from experiments using band steaming for intra-row weed control. They found that steaming of the topsoil was an effective method of reducing weed seed germination, and more effective against weeds in a sandy soil compared to a loamy soil, presumably because of steam penetration, while increasing soil moisture increased the susceptibility of weed seeds to the treatment. However, although steaming appears to have a clear impact on the weed germination, the system has a high energy consumption as well as lethal effects on potentially beneficial soil organisms. Rasmussen (2003) also studied punch planting as a new method to reduce weeds within rows in organically grown crops. In this method, a hole is punched in the soil, and a seed is dropped into it, without any other seedbed preparation and soil disturbance outside the hole. Over two year trials, punch planting with flame weeding, normal planting with flame weeding and normal planting without flame weeding were compared in fodder beet. Punch planting with flame weeding reduced intra-row weed densities by 30% at the 2-4 leaves stage of fodder beet compared to normal drilling with flame weeding, and even by 50% compared to normal drilling without flame weeding (Rasmussen 2003).

Furthermore, crop competition against weeds can be improved by the choice of more competitive crop cultivars, and Rasmussen et al. (2000) state that differences in weed infestation can vary by as much as 25% among different winter wheat as well as spring barley cultivars. Delaying the sowing time of winter cereals by 3 weeks has also been proven to decrease the density and biomass of weeds by 30 to 75%, depending on the weed species composition, etc. (Rasmussen et al. 2000). Since crop yield penalties incurred by this delay amounted to 10% under weed free conditions, however, this method is only appropriate where high weed pressure would otherwise cause a larger yield loss. Placement of slurry in the soil close to the crop rows in spring cereals improved the competitiveness of the cereals against weeds. Without additional weed control, weed biomass was reduced by up to 50% in barley and crop yield increased by 15-35% in barley and oats by astute placement of the manure. Crop rotation influences the weed infestation, i.e. the amount of weeds was lowest in cereals grown the first year after ploughing a clover-grass field, and increased to twice the amount three years after clover-grass (Rasmussen et al. 2000). Very good weed control in cereals can be achieved through a strategy combining pre- and post-emergence harrowing, if necessary augmented by selective harrowing at a later stage, with slurry application close to the crop rows (Rassmusen et al. 2000).

3.1.4. Pest and disease management

- ❖ Most Danish research has focussed on screening for more resistant cultivars, as well as appropriate rotations and plant spacing, etc.
- ❖ Especially in organic fruit and berry production, pests and diseases still cause large yield reductions

Most research into disease management in OF focuses on using resistant varieties, especially as the use of organic pesticides is limited in Denmark compared to other countries in the world, and particularly in fruit and berry production systems, where product quality demands are high and pests and diseases pose the largest challenge (Kühn & Thybo 2001; Petersen 2002; Petersen & Bertelsen 2002). In Danish organic apple orchards, for example, yields are generally only 14 percent of conventional orchard yields (Linhard et al. 2002).

In terms of pest and disease management and product quality of field-grown vegetables, research has also focussed mainly on screening for well-adapted varieties, as well as using catch crops and autumn green manures in the crop rotation (Edelenbos et al. 2003; Sørensen 2003; Sørensen & Thorup-Kristiansen 2003). Danish research into catch crops for vegetable and arable crop cultivation furthermore also addresses aspects of soil biology relevant for crop protection, such as improved living conditions for soil organisms, which may serve as predators for pests (e.g. Axelsen 2003).

Avoiding disease spread in seeds is discussed by Partner 7.

3.2. Livestock production

- ❖ Most research focuses on improvement of animal health and welfare, product quality and genetic improvement of the animals, as well as on utilisation and conservation of biodiversity of marginal areas by grazing
- ❖ Dried chicory provides a potentially viable solution to the sensory off-odour/flavour problem caused by mostly skatole (boar taint)
- ❖ Mixed grazing systems including sows and heifers is usable alternative for grazing sows

The major research emphasis of Danish organic animal or livestock production is concerned with the improvement of animal health and welfare, product quality and genetic improvement of the animals, as well as on the utilisation and conservation of the biodiversity of marginal areas by grazing where relevant.

In 1999, a mixed grazing system with heifers and pregnant sows was compared with grazing systems with heifers and sows alone (Soegaard et al. 2000). Normally, herbage quality used for sow grazing is not optimal for high herbage intake and it was therefore examined whether mixed grazing with heifers could improve the grazing system. Herbage quality and botanical composition of the sward was best where heifers grazed alone, followed by swards with mixed grazing and the poorest quality and composition were in swards where the sows grazed alone. The daily weight gain of the sows tended to be higher and the weight gain of the heifers was significantly higher for mixed than for mono-grazing. The mixed grazing system appears to be a usable alternative for grazing sows.

The use of selected bio-active forages (primarily chicory) with a possible positive influence on health characteristics and meat quality and sensory eating quality of the meat from both steers and fattening/finishing pigs (e.g. CLA, selenium, drip loss and boar taint) has recently been investigated. Hansen et al. (submitted), for example, found that dried chicory – which is comparable in its effect to the crude chicory - was the form of chicory that had the most potential for development as a commercial product in terms of the economic and practical viability of the chicory root as a feedstuff ingredient. Furthermore, the dried chicory root feed has the advantage that the pigs did not need an adaptation period before eating the full amount of 25% dried chicory roots on energy basis. Thus, dried chicory provides a potentially viable solution to the sensory off-odour/flavour problem caused by mostly skatole and known as boar taint, in female and castrated male pork and more important in the large majority of entire male pork (when the pigs have a liveweight at slaughter around 100 kg).

Mogensen & Kristiansen (2002) also tested the effects of barley or rape seed cake as supplement to silage given ad libitum on milk production and health of dairy cows concluded that barley and a mixture of isoenergic rape seed cake and barley had similar feeding value when used as supplement with a high proportion of easily digestible clover grass silage allocated ad libitum and frequently allocation of supplementary feed.

3.3. Organic farming and nature quality

- Herbaceous biodiversity is generally higher on organic compared to conventional farms
- Much of this is probably due to spraying of herbicides and pesticides

One of the common goals of OF is that biodiversity in farmland and adjacent areas must not be compromised and that farm practises support ecosystem functioning, and to a higher extent contribute to nature quality. This, however, is not well documented, and Danish research exists mainly on the biodiversity found in hedgerows and field boundaries (Aude et al. 2003, 2004; Petersen et al. 2004), although Frederiksen & Langer (2004b) also studied the age of other landscape structures within farms. All of these workers concluded that OF is superior to conventional farming with regard to conservation of herbaceous diversity of hedgerows in intensively cultivated agricultural landscapes, with more species that are normal in semi-natural habitats being found on organic farms. Differences between OF and conventional farms observed by Petersen et al. (2004) occurred only 3 to 4 years after conversion to OF, which they felt indicated that herbicide cessation is a major explanatory variable. Furthermore, there was also a tendency towards higher diversity of plant species in the field boundaries that had been managed organically longest.

3.4. Demand for organic products and related health issues

- Among attributes of organic food, such as environmental concerns, animal welfare and food safety or health issues, consumers valued avoidance of chemicals highest
- Multigenerational animal experiments are underway to see if OF has effects on healthiness of produce

The Danish market for organic foods is relatively mature and does not suffer seriously from the supply shortages and barriers that characterise many markets outside Denmark (Weir & Andersen 2003). The well-functioning market also makes it possible to collect and analyse reliable data on purchases, and ongoing studies supported by DARCOF, AKF, UC, GfK Denmark and CIRED France have analysed consumer demand for organic foods in Denmark, both based on observations of stated, as well as actual purchasing behaviour. Relying on the results of a 2002 survey of 400 households across Denmark,Weir & Andersen

(2003) suggest that differences in the shares of organic food consumed is largely related to specific household characteristics. Higher disposable household income (approximated by total food expenditure), age and education level all significantly an increase organic budget share, as does the presence of children younger than 15 years, although the presence of children aged 15 to 20 years (living at home) has the opposite effect. Additionally, household organic shares are higher in urban areas, especially in the capital area, whereas the lowest organic shares were observed in western rural areas of Denmark. Weir & Andersen (2003) also noted that among attributes of organic food, such as environmental concerns, animal welfare and food safety or health issues, avoidance of chemicals was valued highest.

Numerous studies have attempted to elucidate if there is a difference in organically and conventionally produced food in its effect on human health. While many studies support a few general trends of differences in food composition, none have provided any conclusive evidence for differences in the effects on human health. Most of the studies have been inadequate in size or focus to allow any definitive conclusions. The major problem is the complexity of the issue, and the general paucity of knowledge about the impact of food on health, which means that it is virtually impossible to tackle all relevant uncertainties in any one study. Presently, a study detailed in Brandt & Kristiansen (2003) is in progress, which comprises controlled cultivation of plants under three different growing systems for 2 years, and feeding rats for three generations on diets composed of these plants. Ideally it aims to show if food grown under the different growing systems can result in differences in the health of rats, and if so, which aspects of health are affected. However, even if differences are found, subsequent studies will be necessary to determine the applicability and possible consequences for human health. Still, together with other existing and planned studies it might soon be possible to determine some of the production-induced consequences of food to human health, which may ultimately influence demand for organic food.

3.5. Conclusion and perspectives

The main OF studies carried out in Denmark dealt primarily with **biophysical/agronomic issues** trialled on experimental fields across different climatic and edaphic regions, or tested at research institutes and university laboratories, but have also aimed to elucidate more **socio-economic issue**s pertaining to the role of OF within both the agricultural landscape and society as a whole.

The main agronomic (crop) issues concerned:

- optimising short-term productivity while maintaining long-term soil fertility through appropriate crop rotations and cropping patterns
- increasing recycling of resources and reducing nutrient losses
- increasing non-chemical weed control both with and without relying on ploughing
- improving crop resistance to pests and diseases, as well as their natural control

The main research issues pertaining to organic livestock production are involved with

- improvement of animal health and welfare, product quality and genetic improvement of the animals, as well as on the utilisation and conservation of the biodiversity of marginal areas by grazing where relevant
- the use of selected bio-active forages (primarily chicory) with a possible positive influence on health characteristics and meat quality and sensory eating quality of the meat from both steers and fattening/finishing pigs (e.g. CLA, selenium, drip loss and boar taint)

The less immediately agricultural production orientated issues concerned:

- patterns and driving forces of conversion and reversion to and from OF
- elucidate how OF is affecting nature in terms of landscape and biodiversity
- the demand for organic food, and its health value

Generally, research results indicate that the astute choice of crop rotations can both decrease the risk and amounts of nitrate leached, as well as produce sufficient grain yields even without necessarily having to rely on animal manure. Although organic production should ideally include some livestock component(s), as maximising production diversity is certainly one of the organic guiding principles, stockless organic farms are actually become increasingly common. Crop yields are commonly lower in organic production systems, especially in vegetable and fruit husbandry. Indeed, pests and diseases prove difficult to manage in organic fruit and vegetable production, where quality demands are high. More resistant crop cultivars are currently being screened and evaluated, as are cultural methods and rotations that can assist disease and pest management. Non chemical and non tillage weed management systems are also being evaluated, and largely based on the competivity of crop and catch/cover crop cultivars against weeds, as well as using timely planting and spacing, interrow hoeing, band steaming, and punch planting in combination with flame weeding, etc.

3.5.1. Future research

Future research into OF systems must undoubtedly maintain focus on bringing the various individual results and experiences of trials and experiments, as well as participatory socio-economic research related to the Danish farming community, into play into holistic systems on farmers' fields.

Already having a set-up of on-going trials and experiments that investigate a number of diverse agronomic issues and that replicate each other over all the major Danish agricultural soil types and climatic regions certainly is an excellent step towards elucidating more or less suitable crop rotations, crop-livestock systems, etc., for a variety of given environmental and agronomic scenarios and contexts. Possibly, however, the currently only small yield benefits from the use of catch crops may become more significant over time as fertility builds up in the system with catch crops and more nitrate potentially leached or 'caught' and recycled. Additionally, especially where grain legumes are concerned, diseases may well build up over time, and therefore it is curtail that the trials and experiments carry on being conducted over long periods of time. Importantly, it is also important that dynamic simulation models, such as DAISY or FASSET, are further expanded and 'calibrated' against empirical data sets, as these open up the possibility of predicting various scenarios, thereby representing an effective tool to formulate organic production systems that get closer to optimality. Within all this, sight must never be lost from the fact that this information should help serve the farming community at large and therefore ultimately must take their farming, marketing and lifestyle priorities sufficiently into consideration.

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