Design of an organic farming crop rotation experiment

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A field experiment is conducted which focuses on crop rotations for cereal production in organic farming. The objective of the experiment is to explore the possibilities for both short-term and long-term increases in organic cereal production through manipulation of crop rotation design on different soil types. This paper describes the design of a rather complex experiment, and later papers will describe and discuss the results. Three factors are included in the experiment in a factorial design with two replicates: A) fraction of grass-clover and pulses in the rotation (crop rotation), B) catch crop (with or without catch crop or bi-cropped clover), and C) manure (with or without animal manure applied as slurry). All fields in all rotations are represented each year. The experimental factors are defined to allow management to be adjusted for optimisation of the individual treatment combinations. This makes the systems more realistic and the results more applicable in practical farming. The experiment is conducted at four locations representing major soil types and climate regions in Denmark. The main design criteria are related to requirements for a long-term experiment and the need of performing studies and experiments within the experiment itself.

Key words: nitrogen, weed control, slurry, winter wheat (*Triticum aestivum*), spring barley (*Hordeum vulgare*), spring oat (*Avena sativa*), triticale (*Triticosecale*), grass-clover, pea (*Pisum sativum*), lupin (*Lupinus angustifolius*), ryegrass (*Lolium perenne*), catch crop.

Introduction

The most common organic farming system in Denmark is based on a large fraction of grass-clover and fodder crops in the rotation in combination with a stock of ruminant animals, typically for dairy production (Tersbøl & Fog, 1995). This farm type (0.9-1.4 livestock units ha^{-1}) has with proper management proved to sustain a stable crop production with neglible problems (Askegaard et al, 1999). There is, however, a need to increase cereal production in organic farming in order to provide grain for both human consumption and non-ruminant animal feed.

The design and management of organic crop rotations involves many considerations. Contrary to conventional crop production where the management factors can be optimised individually (e.g. fertilisation or weed control), many factors and their interactions must be included in the design and management of organic crop rotations. The main reason is that crop management of organic crop rotations must focus on the prevention of problems like diseases, pests and weeds, rather than the curing of problems. This prevention is based on the construction of sound crop rotations, which are able to reduce the propagation of diseases, and on nitrogen self-supply through the use of N_2-fixing crops and cover crops (Lampkin, 1990). Another very important prevention factor is crop establishment, where a uniform seedbed and the right time of sowing constitute the preconditions for good crop growth and development, which again will improve its competitive ability against weeds.

The options for rotational crops in organic farming include: green manure crops, winter or spring cereals, pulses and oil seed crops, row crops and catch crops. The primary management options in organic crop rotations are manure application, mechanical weed control, straw removal, soil tillage and harvest time (e.g., cereals for maturity or for whole-crop silage). Other factors can, however, also be used to improve the production (e.g., variety choice, seed rate, plant architecture).

There have been only a limited number of studies under temperate conditions in Europe and North America, where different crop rotations have been compared under organic farming or similar production conditions. Examples of recent pure organic rotation trials are the comparison of stockless crop rotations at Elm Farm in England (Bulson et al.,

1996) and the rotations with different fractions of a grass-clover ley in Scotland (Younie et al., 1996). Other factorial experiments have compared organic and integrated or conventional crop rotations. An example of this is the DOC experiment in Switzerland (Besson et al., 1992). Some factorial experiments have looked at the interaction between crop rotation and fertilisation level, e.g. in Norway (Uhlen et al., 1994) and in Poland (Kus & Nawrocki, 1988).

This paper describes the structure and the management of an on-going crop rotation experiment, which was started at four sites in Denmark in 1997. The objective of the experiment is to explore the possibilities for both short-term and long-term increases in organic cereal production through manipulation of crop rotation design on different soil types. The performance of the crop rotations is evaluated in terms of crop production, nutrient leaching and occurrence of weeds, pests and diseases. In addition the experiment functions as workshop facility for other projects concerned with effects of crop rotation design on soil fertility and plant growth. The representation of the crop rotation experiment in terms of soils, climate and farming systems is presented here. The experiment serves a number of purposes and the importance of these for the design of the experiment is discussed. Later papers will present and discuss results of the experiment.

Material and methods

The crop rotation experiment is designed as a factorial experiment with three factors and two replicates where all fields in the rotations are represented every year. The experimental factors are: 1) Fraction of grass-clover and pulses in the rotation (crop rotation), 2) Catch crop (with/without catch crop or bi-cropped clover), and 3) Manure (with/without animal manure as slurry).

Rotations and locations

Four different four-year crop rotations are compared. The contributions of different crop types in the rotations are shown in Table 1 and the actual rotations are shown in Table

2. The ranking of the crop rotations indicates a decreasing input of nitrogen through nitrogen fixation: 1) 1.5 grass-clover and 1 pulse crop, 2) 1 grass-clover and 1 pulse crop, 3) 1 grass-clover crop, and 4) 1 pulse crop. The difference between the grass-clover crops in rotations 1 and 2 is that spring ploughing is used in rotation 1 whereas autumn ploughing is used in rotation 2.

The cereals used in the rotations include spring and winter wheat (*Triticum aestivum*), winter triticale (*Triticosecale*), spring barley (*Hordeum vulgare*) and spring oat (*Avena sativa*). The pulses used include a mixture of pea (*Pisum sativum*) and barley and a pure stand of blue lupin (*Lupinus angustifolius*). All cereals and pulses are harvested as grain or seed crops at maturity.

Care has been taken in preventing diseases being promoted by the crop rotation. Peas (pea/barley) and lupins will alternate from one rotation period to the next. In rotation 4 oat is grown prior to winter wheat in order to minimise the risk of infection with take-all disease (*Gaeumannomyces graminis*). Triticale has been chosen as the second-year winter cereal instead of winter wheat on the sandy soil at Foulum in order to reduce problems with take-all. The choice of varieties is made every year on the basis of a set of prioritised criteria. Typically, high yield characteristics attract lower priority than disease resistance. Preference is given to varieties which have been tested in Denmark for at least 2-3 years.

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

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 cereals or pulses in spring.

The catch crop treatment in rotation 4 is a bi-crop of winter wheat in a pure stand of white clover. The white clover is undersown in oat. After harvest in the autumn and a few days before sowing of winter wheat the clover is cut as short as possible, followed by rotary cultivation in 12 cm wide bands at double normal row spacing (25 cm). The winter wheat is drilled into these bands. The white clover is controlled during the growing season by cutting it separately with a row brush weeder in order to reduce competition with the wheat. After harvest of the winter wheat the clover is allowed to grow and then again a few days before sowing, the same procedure is repeated for the establishment of the second-year winter cereal.

The experiment is carried out at four sites representing different soil types and climate regions in Denmark (Fig. 1). Not all rotations and treatments are carried out at all sites, but rotation 2 is present at all sites (Table 3). The experiment is unirrigated at all sites except Jyndevad, where the irrigation scheduling program MarkVand (Plauborg & Olesen, 1991) is used to define the irrigation demand. All straw and grass-clover production is incorporated or left on the soil in all treatments.

Sowing and fertilisation

The sowing of spring cereals, peas and lupins is carried out as early in the spring as possible, but not before a good preparation of the soil can be performed. The ploughing and the succeeding seedbed harrowing must be very uniform to allow the seeds to be placed at the correct depth and for the weed harrowing to be performed at uniform intensity. The winter cereals are sown as soon as a proper seedbed can be prepared after 25 September. This is slightly later than recommended for conventionally grown cereals in order to reduce weed emergence in autumn.

All the catch crops and the grass-clover mixtures are sown in spring. In the spring cereals the sowing takes place on the same day as the cover crop is sown, except for

Jyndevad where sowing is delayed in order to permit weed harrowing in the rotations with catch crops. Delayed sowing is possible in Jyndevad as the use of irrigation ensures the germination of the catch crops. In the winter cereals the catch crop is sown in April just after the first weed harrowing.

Plots receiving manure are supplied with animal manure (slurry) at rates of ammonium nitrogen in the slurry corresponding to 40% of the nitrogen demand of the specific rotation. The nitrogen demand, based on a Danish national standard (Plantedirektoratet, 1997) is 60, 60, 93 and 113 kg N ha^{-1} as an average of the fields in rotations 1, 2, 3 and 4, respectively. The nitrogen demands of grass-clover and of peas/barley and lupins were set at nil. The predominant type of slurry available at the site is used, either pig slurry, cattle slurry or anaerobically digested slurry. The slurry is distributed evenly between the non-fixing crops in rotations 1 to 3 (Table 8). In rotation 4, however, the winter cereals are favoured at the expense of oat.

In order to obtain a uniform distribution of the slurry to spring cereals it is applied in the seedbed after ploughing and harrowing. Harrowing is performed immediately after application in order to minimise ammonia volatilisation. In winter cereals slurry is applied mid April at the start of growth using trail hoses. Where a wider row distance is used in winter cereals the slurry is placed as close to the rows as possible in order to fertilise the cereals more than the weeds. Harrowing is always performed just before slurry application in order to loosen the soil. This accelerates the infiltration and prevents an uneven penetration of the slurry into the soil.

Plant protection

In the spring sown cereals and pulses where there is no catch crop, weed harrowing is carried out pre and post-emergence and if necessary, once during the later growth stages (Rasmussen & Rasmussen, 1995). In winter cereals without catch crops, pre and post-emergence harrowing is carried out after sowing if the weather permits and if the harrowing can be carried out without covering more than at most 10% of the crop with soil. In addition, one or more weed harrowings are carried out in the spring. These measures proved not to be sufficient on the lighter soils. Therefore in order to facilitate mechanical hoeing between rows, from 1998 larger row distances were used for the winter cereals in rotation 4 at Foulum and for the spring and winter wheat at Jyndevad and from 1999 also for the lupins at Jyndevad (Rasmussen & Pedersen, 1990).

In the winter wheat with catch crops, except for rotation 4, weed harrowing is carried out in the autumn (if possible) and in the spring before sowing the catch crop. At Jyndevad, mechanical weed control is carried out pre and post-emergence in all cereal and pulse crops before the catch crop is sown. In rotation 4, the row brushing carried out to control white clover also controls weeds emerging between the wheat rows.

The sugar beets are kept weed-free by a strategy of pre-emergence flaming, row and hand-hoeing.

If perennial weeds such as creeping thistle (*Cirsium arvense*), mugwort (*Artemisia vulgaris*), curled dock (*Rumex crispus*) and others occur, they are removed manually from the plots. Creeping thistle is removed by cutting the stalk as deep under ground as possible at the time the thistles are budding, which coincides with the time of the anthesis of the cereals. At this time the reserves in the root system are at a minimum (Dock Gustavsson, 1997). If couch grass (*Elymus repens)* occurs in plots without catch crops above a threshold level of 5 shoots m^{-2}, repeated stubble cultivation is carried out after harvest. If couch grass occurs in plots with catch crops above a threshold level of 50 shoots m^{-2} stubble cultivation will be carried out. Another measure to cope with couch grass is to intensify the cutting of the green manure crop. Without occurrence of couch grass the cutting is carried out when the grass-clover has a height of about 15-20 cm in mixtures without red clover and about 20-25 cm in mixtures with red clover. With occurrence of couch grass in the rotation above a threshold of 5 shoots m^{-2}, the cutting is carried out when the grass clover has a height of about 10-15 cm or 15-20 cm, respectively.

Management of the experiment

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

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

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

The experimental treatments were started in 1997. In 1996 a spring barley crop with undersown grass-clover was grown at all sites, except Holeby where a winter wheat crop was grown. No pesticides were used in 1996.

Soil characteristics

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

Results and discussion

Soil characteristics and climate

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

The depth of the A-horizon varies between sites, and also considerably within sites (Table 5). The A-horizon is the upper soil horizon, which is influenced by tillage and which visibly has a larger humus content. The larger average depth of the A-horizon at Foulum and Flakkebjerg is largely caused by very deep A-horizons in parts of the experimental area. These two sites are also the only sites where there is a consistent increase in clay content with increasing soil depth (Table 4). The content of organic matter in the plough layer is about twice as high at Foulum compared with the other sites. The organic matter content does not, however, decrease as rapidly with depth at Flakkebjerg and Holeby as at Jyndevad and Foulum. This indicates considerably deeper rooting on the sandy loam and loam soils at Flakkebjerg and Holeby.

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

The climatic differences are modest across Denmark due to the low relief, but there are some differences between the sites in temperature, precipitation and potential evapotranspiration (Table 7). The mean annual temperature is almost 1°C higher at Holeby compared with Foulum. This covers roughly the span of mean normal temperatures obtained in Denmark. The average annual precipitation varies from 626 mm at Flakkebjerg to 964 mm at Jyndevad. This covers most of the spatial variation in rainfall in Denmark. The spatial variation in potential evapotranspiration is much smaller.

Table 8 shows the application of slurry to the different crops in the rotations. Only cereals and beet receive manure. Different types of slurry are used at the four experimental sites. The actual content of ammonium and total nitrogen in the applied slurry in 1997 and 1998 was used to calculate the livestock density required for production of this manure (Table 8). A slightly higher livestock density was required at Jyndevad, where cattle slurry was used. This was due to the higher content of organic nitrogen in cattle slurry compared with both pig slurry and digested slurry. The estimated livestock densities are lower than on most organic dairy farms in Denmark. The livestock density, however, increases considerably from rotation 2 to rotation 4.

Adjustments of the rotations

Some adjustments in both the design of the rotations and in the management have been made since the start of the experiment in 1997. The policy is that improvements to the rotations and management are permitted as long as the changes do not interfere with the three key factors. After 1997 rotation 1 in Jyndevad was changed from barley, 1st year grass-clover, 2nd year grass-clover, winter wheat to the one presented in Table 2. The reason for this was that crop rotations with a high level of grass-clover already had proved their sustainability (Askegaard et al., 1999). The change made it possible to compare spring wheat in rotation 1 with winter wheat in rotation 2, both following grass-clover and also to compare the pulse crops, lupins in rotation 1 with pea/barley in rotation 2.

In 1998 more clover was introduced into the rotations in order to increase both the N_2-fixation and the diversity. Red clover was added to the grass-clover fields of the heavier soils and four clover species were mixed with the ryegrass catch crop and used in selected crops. From 1999 slurry was applied to winter cereals in mid-April instead of, as earlier, at the start of May. From the colour and growth rate of the winter wheat in the spring it was clear that even following a grass-clover crop, the wheat suffered from N-deficiency at the beginning of the growing season. The row distance was increased at Jyndevad and Foulum in selected crops without catch crops in order to improve the weed control by mechanical hoeing. A successful establishment of the white clover is a prerequisite for the success of rotation 4 (with catch crop). Oat undersown with pure white clover showed a vigorous growth and high competition against the undersown clover at Foulum in 1997 and 1998. The plant density was therefore reduced in 1998 (from 400 to 300 plants m^{-2}). In order to increase yields and reduce problems with take-all, triticale was introduced as the second winter cereal in rotation 4 in 1999 instead of winter wheat.

Design considerations

There were two main considerations in the design of the experiment. The first consideration was related to the wish to continue all or some of the treatments for a long time. In order to investigate the effects of the systems on soil fertility, the experiment should probably be run for at least three rotations, i.e. twelve years (Drinkwater et al., 1995). The second consideration was the requirement to perform other experiments and investigations within the framework of the experimental design, thus investigating the effects of treatments on the dynamics of both soils and plants and related effects on management.

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

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

The sub-division of plots into sub-plots and mini-plots enables experiments and studies to be performed within the systems. The basic requirement for experimental treatments to be carried out in either sub-plots or mini-plots is that they do not have long-term effects on the functioning of the systems. The broad definition of the three main factors in the experiment does, however, allow a large range of management treatments to be applied in sub-plots, including different cereal species, varieties, catch crops, mechanical weed control, strategies for manure application and soil tillage. Mini-plots can probably most efficiently be used for intensive measurements, sampling of plants and soil and for small experiments concerning effects of adding extra nutrients. The advantages of using the crop rotation experiment for such investigations is that it is possible to examine the interactions of such management effects with those of the main cultural factors: rotation, catch crop and manure application.

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Tables

Table 1. Percentages of each rotation comprised of different crop types. Autumn crop cover is defined as permanent white clover understories, grass-clover leys, or catch crops of grass or grass-clover.

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

Table 2. Structure of the four different 4-course crop rotations with and without catch crops. The sign ':' indicates that a grass-clover ley, a clover or a ryegrass/clover catch crop is established in a cover crop of cereals or pulses. The sign '/' indicates a mixture of peas and spring barley or bi-cropping of winter cereals and clover.

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

Table 3. Experiment sites and treatments.

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

Table 4. Soil texture at the four sites at different depths. Particle size fractions, organic matter and calcium carbonate in percent of dry soil.

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

Table 5. Mean depth of the A-horizon formed at the soil surface, and classification of the soils according to the Soil Taxonomy System (Nielsen & Møberg, 1985). The values in brackets are standard deviations.

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

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

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

Table 7. Normal monthly and annual air temperature, precipitation and potential evapotranspiration at Jyndevad (Jy), Foulum (Fo), Flakkebjerg (Fl) and Holeby (Ho) for the period 1961-90 (Olesen, 1991). The normal climate for Holeby was taken from the station at Abed. The precipitation is corrected to ground level according to Allerup & Madsen (1979), and the potential evapotranspiration was calculated using a modified Priestly-Taylor formula (Aslyng & Hansen, 1982).

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

Table 8. Application of slurry to the crops in the four rotations in NH_4-N and in corresponding livestock density (LU ha^{-1}) at Jyndevad (Jy), Foulum (Fo), Flakkebjerg (Fl) and Holeby (Ho). One livestock unit (LU) corresponds to 100 kg of total N in manure produced per year.

	Crop rotation			
	1	2	3	4
Crops receiving slurry	NH_4-N in slurry (kg ha^{-1} yr^{-1})			
Spring barley	50	50	50	-
Spring wheat	50	-	-	-
Spring oat	-	-	-	40
Winter cereals	-	50	50	70
Beet	-	-	50	-
Average in rotation	25	25	38	45
Slurry type	Livestock density (LU ha^{-1})			
Cattle slurry (Jy)	0.5	0.5	-	-
Pig slurry (Fo, Ho)	-	0.4	0.6	0.7
Digested slurry (Fl)	-	0.4	0.6	0.7

Figure legends

Fig. 1. Location of the four experimental sites in Denmark.

Fig 2. Plot infrastructure at the four experimental sites with sub-plots and mini-plots. Both sub-plots and mini-plots are numbered. The harvest parts of the plots are shown in dark shading. The part containing mini-plots are shown in light shading. The size of each mini-plot is 1 m^2.