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Crop production during the first course of an organic crop rotation trial in Denmark

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Summary

Three factors are included in a factorial field experiment: 1) fraction of grass-clover and pulses in the rotation (crop rotation), 2) catch crop (with or without catch crop), and 3) manure (with or without animal manure). Manure is applied as slurry in rates corresponding to 40 % of the nitrogen demand. Grain yields for three sites and three years of the experiment are presented for two four-course rotations. One rotation has a green-manure crop, which is replaced by winter wheat in the other rotation.

The use of manure significantly increased grain yield of the cereal crops in most cases. The positive effects of the catch crops were mainly observed in the spring cereals. The largest rotation yields were obtained in the crop rotation without a green manure crop. The positive effect of a green manure crop could not substitute for the yield decrease from leaving 25% of the area out of production.

Key words: Organic farming, crop rotation, cereals, pulses, grain yield, catch crop, manure.

Introduction

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

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

There have only been a limited number of studies under temperate conditions in Europe and North America, where different crop rotations have been compared under organic farming or similar production conditions. Examples of recent pure organic rotation trials are the comparison of stockless crop rotations at Elm Farm in England (Bulson, Welsh, Stopes & Woodward, 1996), and the rotations with different fractions of grass-clover ley in Scotland (Younie, Watson & Squire, 1996).

An organic farming crop rotation trial was initiated in Denmark in 1997. This paper presents the crop yields of two of the tested rotations at three sites for the first three years of the experiment.

Materials and Methods

The crop rotation experiment is designed as a factorial experiment with three factors where all fields in the rotations are represented every year (Olesen, Askegard and Rasmussen, 2000). The experimental factors are (1) fraction of clover grass and pulses in the rotation (crop rotation), (2) catch crop (with and without catch crop or bi-cropped clover) and (3) manure (with and without animal manure applied as slurry).

Four different four-year crop rotations are compared. However, only results from two of the rotations are presented here (Table 1). These two rotations differ with respect to the use of a grass/clover green manure, which is present in rotation 2, but not in rotation 4. All fields in all rotations are represented every year.

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

The plots receiving manure are supplied with slurry at rates corresponding to 40% of the nitrogen demand of the specific rotation. The nitrogen demand is based on a Danish national standard (Plantedirektoratet, 1997). The nitrogen demands from grass-clover and from peas/barley are set to nil. In rotation 2 spring barley and winter wheat each received slurry corresponding to 50 kg NH_4-N ha^{-1}. In rotation 4 the application rates were 40 and 70 kg NH_4-N ha^{-1} for spring oats and winter cereals, respectively.

Results are presented for three sites representing different soil types and climate regions in Denmark. Jyndevad is located in Southern Jutland and represents a coarse sandy soil with an average annual rainfall of 964 mm. Crop rotation 4 is not represented at Jyndevad. Foulum is located in Central Jutland on a loamy sand with an annual rainfall of 704 mm. Flakkebjerg is located in Western Sealand on a sandy loam with an annual rainfall of 626 mm. The experiment is unirrigated at all sites except Jyndevad. All straw and grass-clover production is incorporated or left on the soil in all treatments.

Table 1. *Crop rotations with and without catch crops. The sign ':' indicates that a grass-clover ley, or a clover, ryegrass or 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	Rotation 2	Rotation 4
Without	S. barley:ley	Spring oat
	Grass-clover	Winter wheat
	Winter wheat	Winter cereal[1]
	Pea/barley	Pea/barley
With	S. barley:ley	S. oat:clover
	Grass-clover	W. wheat/clover
	W. wheat:Grass	W. cereal/clover[1]
	Pea/barley:Grass	Pea/barley:Grass

[1]: winter wheat except at Foulum in 1999, where triticale was grown in stead.

Weeds in cereals and pulses without catch crops are mainly controlled by harrowing. Large weed plants (e.g. creeping thistle *Cirsium arvense* and mugwort *Artemisia vulgaris*) are controlled by manual weeding. Couch grass (*Elymus repens*) if present is controlled by repeated harrowing after harvest in plots without catch crops. If the density of couch grass exceeds a threshold in any given year, the catch crop is omitted and mechanical weed control is performed in the autumn.

Each plot is sub-divided into three to five sub-plots. The grain yield of cereals and pulses are measured at harvest maturity in two sub-plots in each plot using a combine harvester. The size of the net harvest plots varies between sites from 16 to 58 m^2.

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

Results

The grain yield of the individual cereal crops is shown in Tables 2 to 6. Manure application significantly increased grain yield in most cases.

The yield of spring barley declined over time in the system without manure and catch crops, whereas yields of the other systems seem to have stabilised (Table 2). The highest and most stabile yields were obtained in the system with use of catch crops.

There were no significant effects of catch crop on winter wheat yields in rotation 2, and the average results for the two manure treatments are therefore presented in Table 3. The yields increased considerably from 1997 to 1998. This is due to the fact that all sites in 1996 were grown with spring barley undersown with grass/clover. This did not provide a full preceding green manure crop in 1997. The clover in the green manure failed to establish at Flakkebjerg in 1997, which is the reason for the lower winter wheat yields at this site in 1998.

The yield of spring oats varied considerably between the years, especially in the systems without catch crops. The lower yields in 1997 in the system without catch crops is possibly due to damage to the crop caused by the early weed harrowing. The yields of oats in the un-manured systems were considerably higher that the corresponding yields for spring barley (compare Tables 2 and 4). There was a significant yield increase for catch crop in 1999 at Flakkebjerg, but not at Foulum.

Table 2. *Grain yield of spring barley in crop rotation 2 (g DM m^{-2}).*

Location	Year	Without catch crop		With catch crop		SE
		No manure	Manure	No manure	Manure	
Jyndevad	1997	260	321			32
(sand)	1998	120	143	149	194	8
	1999	108	203	189	337	22
Foulum	1997	303	391			87
(sandy loam)	1998	398	479	380	532	32
	1999	162	317	310	361	17
Flakkebjerg	1997	187	356			18
(loamy sand)	1998	248	282	221	287	15
	1999	124	283	211	369	17

Table 3. *Grain yield of winter wheat in crop rotation 2 (g DM m^{-2}).*

Location	Year	No manure	Manure	SE
Jyndevad	1997	132	244	12
(sand)	1998	291	330	33
	1999	269	333	11
Foulum	1997	223	363	59
(sandy loam)	1998	449	573	19
	1999	411	528	39
Flakkebjerg	1997	252	330	37
(loamy sand)	1998	305	332	15
	1999	444	492	6

Table 4. *Grain yield of spring oats in crop rotation 4 (g DM m^{-2}).*

Location	Year	Without catch crop		With catch crop		SE
		No manure	Manure	No manure	Manure	
Foulum	1997	250	285	240	369	29
(sandy loam)	1998	422	516	387	515	23
	1999	413	499	464	497	23
Flakkebjerg	1997	165	239	203	417	12
(loamy sand)	1998	306	321	286	362	12
	1999	227	408	339	440	32

The grain yields of the first-year winter wheat in rotation 4 were generally low, and sligthly declining over time in the system without manure application (Table 5). There were no significant effects of the bi-cropping system on grain yield. Slightly lower yields were obtained in the second-year winter cereal (Table 6). The yield of the bi-cropping system failed at Foulum, especially where manure was applied. This may have been caused by both high incidences of take-all and by competition with grass weeds (primarily ryegrass), which was much more dominant during the second year bi-cropping than during the first year.

Table 5. *Grain yield of first-year winter wheat in crop rotation 4 (g DM m^{-2}). The systems with catch crops are bi-cropping of winter wheat and white clover.*

Location	Year	Without catch crop		With catch crop		SE
		No manure	Manure	No manure	Manure	
Foulum	1997	252	454	236	321	85
(sandy loam)	1998	273	469	283	427	24
	1999	252	435	261	424	20
Flakkebjerg	1997	239	374	248	393	32
(loamy sand)	1998	254	308	200	278	16
	1999	206	356	184	407	10

The grain yield of the pea/barley mixture grown for maturity was unaffected by manure application during the preceding years. Results are therefore presented in Table 7 for the effects of rotation and catch crop. There were significant interactions between these factors at Flakkebjerg in 1998 and 1999. This resulted in higher yields in the catch crop treatment in rotation 4 compared with the other treatments and rotations. The lowest yield in 1999 at Flakkebjerg was obtained in rotation 4 in the system without catch crops. This occurred primarily because of failure of the pea component to compensate for lower barley yields under low nitrogen fertility. This failure may have been caused by relatively dry conditions and possibly poor root development at Flakkebjerg, because such factors are the main determinants of N_2-fixation and yield in pea (Jensen, 1997).

Table 6. *Grain yield of second-year winter cereal in crop rotation 4 (g DM m^{-2}). The winter cereal was winter wheat, except for Foulum in 1999 where triticale was grown. The systems with catch crops are bi-cropping of winter wheat and white clover.*

Location	Year	Without catch crop		With catch crop		SE
		No manure	Manure	No manure	Manure	
Foulum	1998	205	445	136	170	56
(sandy loam)	1999	191	427	171	274	5
Flakkebjerg	1998	210	240	136	162	5
(loamy sand)	1999	189	373	155	344	15

Table 7. *Grain yield of pea/barley in crop rotations 2 and 4 (g DM m^{-2}).*

Location	Year	Rotation 2		Rotation 4		SE
		No catch crop	Catch crop	No catch crop	Catch crop	
Jyndevad	1997	316	358			48
(sand)	1998	352	353			15
	1999	315	346			18
Foulum	1997	374	353	377	361	26
(sandy loam)	1998	473	482	470	489	9
	1999	392	364	357	360	8
Flakkebjerg	1997	278	350	303	305	18
(loamy sand)	1998	331	332	342	462	18
	1999	341	292	250	342	25

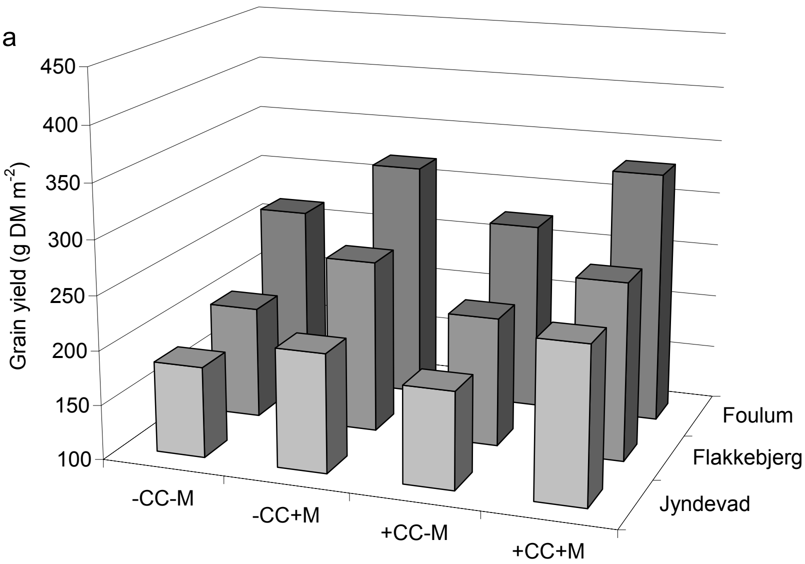
The grain yields of all cereal and pulse crops as average of the rotation are shown in Tables 8 and 9 for interactive effects of crop rotation with manure application and catch crops, respectively. The average grain yields were calculated by summing of the grain yields over all fields in the rotation and dividing by the area (including the area of the green manure crop).

Table 8. *Mean grain yield for all cereal and pulse crops in the two crop rotations (g DM m^{-2}).*

Location	Year	Rotation 2		Rotation 4		SE
		No manure	Manure	No manure	Manure	
Jyndevad	1997	181	227			20
(sand)	1998	193	214			9
	1999	184	236			10
Foulum	1997	226	276	276	367	44
(sandy loam)	1998	328	390	334	435	18
	1999	256	312	311	407	13
Flakkebjerg	1997	202	277	224	297	22
(loamy sand)	1998	215	240	268	315	7
	1999	228	289	236	366	8

Table 9. *Mean grain yield for all cereal and pulse crops in the two crop rotations (g DM m^{-2}).*

Location	Year	Rotation 2		Rotation 4		SE
		No catch crop	Catch crop	No catch crop	Catch crop	
Jyndevad	1997	193	215			20
(sand)	1998	201	206			9
	1999	193	227			10
Foulum	1997	251	251	338	306	43
(sandy loam)	1998	353	365	407	362	18
	1999	275	292	366	351	13
Flakkebjerg	1997	218	230	262	292	22
(loamy sand)	1998	226	229	291	294	7
	1999	228	264	282	319	8



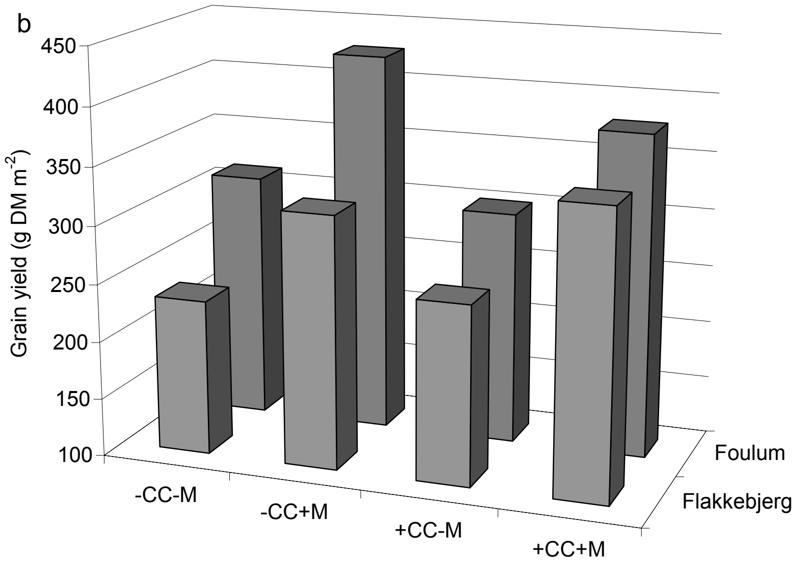


Fig. 1. Average grain yield over all fields in rotation 2 (a) and rotation 4 (b) as affected by site and treatment. The treatments are with (+CC) and without (-CC) catch crop and with (+M) and without (-M) manure. Mean of 3 years.

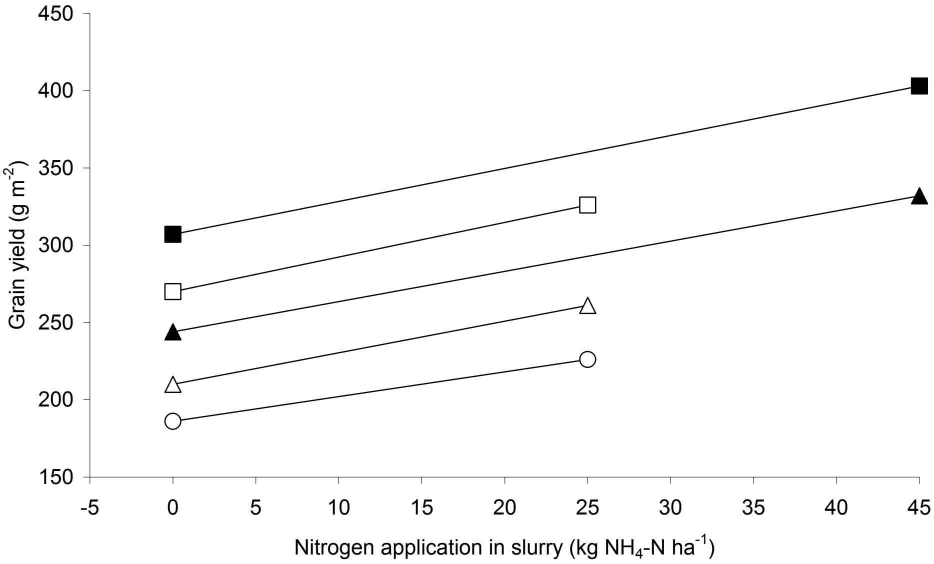


Fig. 2. Response of average grain yields in the rotations to rate of manure application. Open symbols denote rotation 2 and filled symbols denote rotation 4. The circles denote results from Jyndevad, squares Foulum and triangles Flakkebjerg.

Average grain yields in rotation 2 were lowest at Jyndevad and highest at Foulum (Fig. 1). For rotation 2 grain yields were significantly higher at all locations in the catch crop system in 1999 (Table 9). A similar effect was also observed for rotation 4 at Flakkebjerg, but not at Foulum.

The average grain yields of the different rotations responded identically to increasing rates of nitrogen applied in the slurry as shown by the parallel lines in Fig. 2. The response of grain yield to manure application was estimated by linear regression as 2.0 g m^{-2} (kg NH_4-N $ha^{-1})^{-1}$.

The average yields obtained were higher for crop rotation 4 compared with rotation 2, even when adjusted for effect of the rate of manure application (Figs 1 and 2). There were, however, some years where the difference between yields of the un-manured systems was very small.

Discussion

Total grain yield of the cereal and pulse crops in the tested rotations were affected by all experimental factors (rotation, manure and catch crop). The largest effects on yield were, however, caused by differences between sites caused by differences in soils, climate and cropping history. The lowest yields were obtained at Jyndevad on the coarse sandy soil, where losses of nitrogen due to leaching is high (Hansen, Kristensen, Grant, Høgh-Jensen, Simmelsgaard & Olesen, 2000). The experimental area at Flakkebjerg was previously grown with cereals only, whereas the area at Foulum was part of a mixed crop rotation that also included grass and grass/clover. This is probably the reason for the higher yields at Foulum compared with Flakkebjerg.

Crop rotation 2 has a large N-input through the nitrogen fixation in the grass/clover green manure. The positive effects of this on yield of the following cereals were not enough to compensate for the lower overall yield from effectively leaving 25% of the rotational area out of production. This situation may, however, change over time as soil fertility builds up in rotation 2 and is depleted in rotation 4. There are no clear indications that this has affected the results of the first three years of the experiment. The results are in accordance with results of a simulation study performed by Høgh-Jensen (1999) that showed that the ley proportion of a stockless crop rotation should not exceed 11% to give maximum total yield.

The estimated response of grain yield to manure application of 2.0 g m^{-2} (kg NH_4-N $ha^{-1})^{-1}$ is about twice as high as the response estimated by Tersbøl & Kristensen (1997) using data from surveys on arable organic farms in Denmark. Their unfertilised yield on sandy loam soils was 270 g DM m^{-2} for rotations low in frequency of grass/clover crops. This yield level is very similar to the yields obtained here (Table 8). The lower yield response to manure in the on farm studies may have occurred partly because of lower utilisation efficiencies under the on-farm conditions and partly because the effect of manure gets obscured by other interacting effects.

The effects of the catch crops on total grain yield were smaller than the effects of crop rotation and manure application (Fig. 1). The effect of catch crop in rotation 2 was, however, positive and significant at all locations in 1999. The effect of catch crop in rotation 4 was significantly positive at Flakkebjerg in 1999, but significantly negative at Foulum in 1998. These mixed results in rotation 4 are caused by failure of the cereal:clover bi-cropping system to provide yield benefits. This system was designed as a low-input system mainly for silage production (Clements, Martyn, Balsdon, George & Donaldson, 1996). The system was most prone to failure in the second year winter cereal, partly due to problems with grass weeds and partly due to large incidences of take-all, which in some cases were higher in the bi-cropping system compared with the ploughed system without catch crops. These problems suggest that crop rotation 4 can be optimised by reducing the proportion of winter cereals in the rotation and by avoiding bi-cropping during several years.

The initial results of the crop rotation experiment show large differences in response between the different sites. Further effects are expected to be caused by long-term effects on soil fertility and will therefore take a long time to be manifested in the experiments. The experiment will probably have to continue for at least ten years to give adequate information on the long-term sustainability of crop rotations for organic cereal production.

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