Learning from a long-term crop rotation experiment

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Abstract

A crop rotation experiment was established in 1996/97 at three locations representing different soil types and climates. Three factors were tested: i) crop rotation with different proportions of N_2-fixing crops, ii) with and without a catch crop, and iii) with and without animal manure. A green manure crop increased yields in the following cereal crops, but at the rotational level, total yields were larger in crop rotations without a green manure crop. There were positive effects of animal manure and catch crops on yield. However, except for the coarse sandy soil, the yield effects of catch crops and animal manure decreased over time when a grass-clover green manure was included in the rotation. The problems with perennial weeds increased over time depending on crop rotation and use of catch crops. This stresses the importance of considering long-term effects in the evaluation of crop management measures.

Keywords: Crop rotation, cereals, nutrients, weeds, management

Introduction

Crop production in organic farming systems relies to a large extent on soil fertility for nutrient supply. The soil fertility must be maintained via choice of crop rotation and (green) manuring practices. Fertility building by such means requires a long-term integrated approach, rather than the short-term and targeted solutions common in conventional agriculture. The control of perennial weeds is another area, which requires a long-term perspective, since there are interactions with the soil fertility and with crop management. Enhanced soil fertility has been found to increase crop yields in organic farming (Olesen et al, 2002). However, higher soil fertility may also increase the negative environmental impacts, including nitrate leaching and nitrous oxide emissions. It follows that, for studies of management effects in organic cropping systems and their environmental impacts, long-term cropping experiments are indispensable.

Materials and methods

A crop rotation experiment was established in 1997 at three locations in Denmark representing different soil types and climates: a coarse sand at Jyndevad, a loamy sand at Foulum and a sandy loam at Flakkebjerg. Average precipitation was 964, 704 and 626 mm at Jyndevad, Foulum and Flakkebjerg, respectively (Olesen et al, 2000). The following experimental factors were included in a factorial design with two replicates and all crops in the rotations were represented every year: i) crop rotation, with different proportions of N_2-fixing crops, ii) with (+CC) and without catch crop (-CC), and iii) with (+M) and without animal manure (-M) applied as slurry. Different four-year crop rotations were compared in the experiment, and two courses of the rotations were completed in 2004. Results from two different crop rotations are presented here, rotation 2 (R2: spring barley undersown with grass-clover – grass-clover – winter cereal – pulse crop) and rotation 4 (R4, 1st course: spring oat – winter wheat – winter cereal – pulse crop, and R4, 2nd course: spring barley – pulse crop – winter cereal – spring oat). Cereal and pulse crops were harvested at maturity. All straw and grass-clover production was incorporated or left on the soil. The +M treatments received anaerobically stored slurry at rates, where the NH_4-N application corresponded to 40% of the N demand of the specific rotation according to a Danish national standard. The N demands of grass-clover, peas/barley and lupin/barley were set to nil.

Results

There were limited problems with pests, diseases, and annual weeds and increasing problems with perennial weeds during the two courses. The average yields in R2 decreased from the first to the second course at Jyndevad and Foulum (Table 1), primarily due a change in pulse crop species. At Flakkebjerg, the yields in R2 increased over time due to improved soil fertility. The average grain yields were higher in R2 compared with R4. However, the benefits from the green manure could not compensate for the average yield reduction caused by leaving 25% of the rotation out of production. As a rotational mean, including zero yield in the green manure crop, R2 yielded 14 to 18% less than R4.

Table 1. Mean grain yield of cereal and pulse crops and mean yield increase from catch crops and manure application (t DM/ha) in the two crop rotations for two courses of the rotations.

Course	Location	Rotation R2			Rotation R4		
		Mean	Yield increase		Mean	Yield increase	
		Yield	CC	Manure	Yield	CC	Manure
1st	Jyndevad	2.87	0.20	0.65			
(1998-2000)	Foulum	4.20	0.13	0.79	3.64	-0.23	1.01
	Flakkebjerg	3.34	0.06	0.50	3.06	0.21	0.90
2nd	Jyndevad	2.42	0.06	0.96			
(2001-2004)	Foulum	3.90	0.05	0.55	3.64	0.63	0.82
	Flakkebjerg	3.59	0.08	0.41	2.90	0.64	0.89

The use of catch crops in R2 increased yields in the first course at all locations, most at Jyndevad and the least at Flakkebjerg (Table 1). This difference between locations was probably due to large nitrate leaching losses from the sandy soil (Askegaard et al, 2005). In the second course of R2, the use of catch crops caused a yield decrease in the winter wheat following the grass-clover crop at Foulum and Flakkebjerg. However, at Flakkebjerg this yield decrease was nearly matched by a yield increase in the spring barley crop. Thus, as an average of R2, there was only a small effect of catch crop on yields. This result can probably be ascribed to a buffering effect of the clover in the grass-clover crop. A higher yield in the spring barley reduced the clover content in the grass-clover, which was established by undersowing it in the barley crop. This subsequently reduced the nitrogen supply to the following winter wheat.

The catch crops in R4 were clover-based and contributed to the N supply through N_2-fixation. The ploughing-in of clover catch crops prior to spring cereals increased yields in both the 1st and the 2nd course (Table 1). The negative effect of catch crops in the winter cereals in the 1st course of R4 derived from problems in the bi-cropping of winter cereals in a stand of clover. The method was changed in the 2nd course, which led to a positive effect of the catch crop on yields, also of the winter wheat.

Yields increased significantly after manure application in both R2 and R4, but the effect decreased from the 1st to the 2nd course at Foulum and Flakkebjerg (Table 1). This reduction probably resulted from the manure application affecting the proportion of clover in the grass-clover in R2 and the clover-dominated catch crops in R4. On the coarse sand at Jyndevad there was no such effect.

At Jyndevad, the infestation of couch grass (*E. repens*) quickly developed into a problem, whereas the infestation of *E. repens* developed slower at Flakkebjerg and to a much lesser extent at Foulum (Table 2). Stubble cultivations in the plots without catch crops were performed in autumn during most years at both Jyndevad and Flakkebjerg to control perennial weeds. This decreased *E. repens* infestations, but increased nitrate leaching significantly at Jyndevad from 30 kg N/ha in the +CC treatment to 130 kg N/ha in the –CC treatment (Askegaard et al, 2005). In spite of the high level of *E. repens* infestations in the +CC treatments at Jyndevad, the mean of cereal and pulse yields where higher in the +CC than in the –CC treatments in the second course of the rotation (Table 1), probably because of an improved nutrient supply. However, the yield benefit from catch crops at Jyndevad decreased from the first to the second course of the rotation, and this may be at least partly explained by the increase in *E. repens* infestations in the catch crop treatments. Manure affected *E. repens* differently at the two sites, giving increasing shoot densities in R2 at Flakkebjerg and decreases at Jyndevad (Table 2).

At Flakkebjerg, there was a lower infestation of thistles (*C. arvense*) in rotation 2 than in rotation 4, with least biomass in the crop the year after grass-clover (Table 2). There was a tendency for lower number of thistle shoots in the +CC treatment compared with the -CC treatment in rotation R4 (Table 2), in spite of the fact that stubble cultivations and row hoeing were carried out in the –CC and not in the +CC treatments. This most likely occurred because the nutrients retained in the topsoil by the catch crops benefited the crops, then which became more competitive against the thistles. Manure application reduced the thistle shoot density.

Table 2. Mean density of shoots of couch grass (*E. repens*) and thistles (*C. arvense*) and mean density increase from catch crops and manure application (no/m^2) in the two crop rotations for two courses of the rotations.

Course	Location	Rotation R2			Rotation R4		
		Mean	Increase		Mean	Increase	
			CC	Manure		CC	Manure
E. repens							
1st (98-00)	Jyndevad	10.7	8.4	-7.7			
	Flakkebjerg	1.3	0.9	0.3	1.2	0.4	1.3
2nd (01-04)	Jyndevad	23.9	28.0	-12.9			
	Flakkebjerg	5.3	4.9	5.0	7.3	10.5	-1.3
C. arvense							
1st (99-00)	Flakkebjerg	0.6	-0.5	-0.5	1.3	-1.6	-0.2
2nd (01-04)	Flakkebjerg	1.1	0.5	-0.1	2.2	-1.5	-1.1

Discussion

The experiment has demonstrated that the long-term effects of different cropping systems are different from the short-term effects. These differences result from effects of the different cropping systems on soil fertility and on infestation with perennial weeds. Many of the effects were related to nutrient supply, in particular nitrogen supply. These effects depended on site conditions as influenced by soil type and climate. For the coarse sandy soil and the high rainfall at Jyndevad, nitrate leaching had a considerable effect on crop nitrogen supply and this was probably the main reason for the low yields at this site. The nitrate leaching was much less of a problem for the sandy loam and the lower rainfall at Flakkebjerg, where yields in some years instead were restricted by low summer rainfall.

The buffering effect of the grass-clover in rotation R2 resulted in smaller yield benefits from both catch crops and manure application in the 2nd compared with the 1st course of the experiment. This suggests that improving soil fertility via grass-clover green manure crops may not be the best way to improve crop yields. Instead the plant material from the grass-clover crops may be harvested and used in biogas digesters for renewable energy supply, and the digested slurry may be applied in a more targeted way to improve crop yields, possibly without loosing the yield benefits from growing catch crops.

Improved nutrient supply increased the crop competitiveness against *E. repens*. However, this was not sufficient to control this weed species, and stubble cultivations were necessary, in particular at the coarse sandy soil at Jyndevad. However, stubble cultivations in autumn increase the risk of nitrate leaching, which may further reduce crop nitrogen supply and reduce crop competitiveness. There is a need to break this vicious cycle, and growing catch crops may be a solution, if they can be effectively established after the stubble cultivations. An alternative is to perform the mechanical control of *E. repens* in spring prior to sowing, possibly by harvesting or burning the rhizomes.

Both the grass-clover green manure and the use of catch crops reduced the occurrence of *C. arvense*. These components of the crop rotation should therefore be considered in cases, where there is risk of infestation with *C. arvense* and possibly with other deep-rooted perennial weeds.

Conclusions

The yield effects of catch crops and manure changed from the first to the second course of the organic crop rotation experiment. This stresses the importance of considering long-term effects in the evaluation of crop management measures. The results of the crop rotation experiment demonstrate that crop management practices, including crop rotation design, should be tailored to the local site conditions. These site conditions not only include soil type and climate, but also the soil fertility and the specific weed problems.

References

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