Crop rotation and crop management effects on cereal yields in arable organic farming in Denmark

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Abstract

One of the main challenges in organic crop production is to ensure high and stable crop yields. In this study we used data from a 12 year old crop rotation experiment in Denmark to estimate the contribution of various management factors to yields of winter and spring cereals. The experiment included three factors in two replicates: 1) Grass-clover green manure crop (with and without), 2) catch crop (with and without), and 3) animal manure (with and without). Animal manure was the most important factor for increasing grain yield of cereal crops, but also grass-clover and catch crop contributed considerably to increasing yields. The grass-clover had a larger long-term effect on grain yields on the sandy loam soils than on the sandy soil. Yields were significantly reduced by weeds, and maintaing stable yields requires good weed control and prevention measures.

Introduction

An expansion of organic crop production requires increased crop production, which calls for high and stable crop yields if this is to take place without expanding agricultural area. This must be achieved while ensuring integrity of the organic crop production, placing less reliance on external and non-renewable resources and reducing environmental effects of the production system. Studies undertaken in Europe have pointed to restricted nitrogen (N) supply and poor weed control as being the primary reasons for low yields in organic cereal crops (Olesen et al., 2007, 2009). Improving the crop rotation design through inclusion of green manure crops and catch crops may contribute to a sustainable increase of cereal crop yields. In this study we used data from a 12 year old crop rotation experiment in Denmark to estimate the contribution of various management factors to yields of winter and spring cereals.

Materials and methods

An experiment on organic arable crop rotations was conducted at three sites in Denmark from 1997 to 2008 (Olesen et al., 2000). The experiment included three factors in two replicates: 1) Grass-clover green manure crop (with and without), 2)

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catch crop (with and without), and 3) animal manure (with and without). Four year crop rotations were used (Table 1), and all crops in the rotations were represented every year. The experiment was placed at three sites with different soil and climatic conditions: Jyndevad (sand), Foulum (loamy sand) and Flakkebjerg (sandy loam). Crop rotation O1 was only used at Jyndevad in 1997-2004 and was replaced by O4 in 2005-2008. Where manure was applied this corresponded to about 40-60% of the recommended rates in conventional farming.

The content of ammoniacal N (NH_4-N) in the applied manure was determined. Grain yields were determined for each plot by combine harvester. Samples of above ground biomass were taken in each plot at ear emergence in the cereals, and the samples were separated into cereal, catch crop and weeds for assessing weed pressure.

The harvested dry matter grain yields were related to applied ammoniacal N in the manure and to the assessed weed pressure (percent weed of total biomass). Additional effects of grass-clover and catch crops in the rotation was also included in the statistical analyses. For winter cereals it was possible to separate the effect of grass-clover in a direct pre-crop effect and in a longer-term effect of having grass-clover in the rotation. All analyses were performed using a mixed regression model and applying the MIXED procedure of the SAS statistical analysis system. The model included linear effects of applied ammonium in manure and of percent weeds present, categorical effects of grass-clover as pre-crop or in the rotation and of catch crops.

Tab. 1: Organic crop rotations during 1997 to 2009 at Jyndevad, Foulum and Flakkebjerg.

Course	O1	O2	O4
1st course	S. barley/ley	S.barley/ley	S.oat^CC
1997-2000	Grass-clover	Grass-clover	W. wheat^CC
	S. wheat^CC	W. wheat	W. cereal^1 CC
	Lupin^CC	Pea/barley^CC	Pea/barley^CC
2nd course	S. barley/ley	S.barley/ley	W. wheat^CC
2001-2004	Grass-clover	Grass-clover	S. oat^CC
	S. oat^CC	W. cereal^2	S. barley^CC
	Pea/barley^CC	Lupin^CC	Lupin
3rd course		S.barley/ley	S. barley^CC
2005-2008		Grass-clover	Faba bean^CC
		Potato	Potato
		W. wheat^CC	W. wheat^CC

[1] Triticale at Foulum, wheat at Flakkebjerg, [2] Rye at Jyndevad, otherwise wheat
^CC Catch crop

Results and discussion

The largest effect of manure application was achieved at Foulum for the winter cereals (Table 2), but at Jyndevad for the spring cereals (Tables 3 and 4). At Foulum and Flakkebjerg similar effects of manure application were achieved in all cereal crops. The applied rates of manure application in the experiment were mostly around 50 kg NH_4-N/ha. This manure rate gave yield increases of 0.9 to 1.4 Mg DM/ha in winter cereals, 0.9 to 1.5 Mg DM/ha in spring barley and 1.1 to 1.7 Mg DM/ha in spring oats.

Tab. 2: Effects of animal manure, grass-clover, catch crops and weeds on dry matter yields in winter cereals (winter wheat, winter rye and winter triticale).

	Jyndevad		Foulum		Flakkebjerg	
Manure (kg DM/kg NH_4-N)	19	***	28	***	17	***
Grass-clover pre-crop (kg DM/ha)	1312	**	626	***	858	***
Grass-clover in rotation (kg DM/ha)	162	NS	600	***	778	***
Catch crop in rotation (kg DM/ha)	37	NS	60	NS	105	NS
Weeds (kg DM/% weed)	-14	**	-66	***	-37	**

Levels of significance: NS: P>0.05, *: 0.05>P>0.01, **: 0.01>P>0.001, ***:0.001>P.

Tab. 3: Effects of animal manure, grass-clover, catch crops and weeds on dry matter yields in spring barley.

	Jyndevad		Foulum		Flakkebjerg	
Manure (kg DM/kg NH_4-N)	29	***	18	***	19	***
Grass-clover in rotation (kg DM/ha)	6	NS	384	***	274	**
Catch crop in rotation (kg DM/ha)	603	***	689	***	433	***
Weeds (kg DM/% weed)	-36	***	-72	***	-29	*

Levels of significance: NS: P>0.05, *: 0.05>P>0.01, **: 0.01>P>0.001, ***:0.001>P.

Tab. 4: Effects of animal manure, grass-clover, catch crops and weeds on dry matter yields in spring oats.

	Jyndevad		Foulum		Flakkebjerg	
Manure (kg DM/kg NH_4-N)	33	***	22	***	23	***
Catch crop in rotation (kg DM/ha)	42	NS	838	***	729	***
Weeds (kg DM/% weed)	-91	**	-64	*	-31	NS

Levels of significance: NS: P>0.05, *: 0.05>P>0.01, **: 0.01>P>0.001, ***:0.001>P.

Grass-clover in the rotation gave only small yield increases at Jyndevad. This may be explained by the large loss of N accumulated in the grass-clover crop by N-leaching following ploughing of the grass-clover ley (Askegaard et al., 2005). However, the grain yield effects of grass-clover as a pre-crop to winter cereals was larger at Jyndevad than at the other two sites. The combined effect of grass-clover as a pre-crop and grass-clover in the rotation on winter cereal grain yield was 1.5, 1.2 and 1.6 Mg DM/ha at Jyndevad, Foulum and Flakkebjerg, respectively. This is similar to the effect of applying manure at a rate of 50 kg NH_4-N/ha. However, the amount of N recycled in the grass-clover was about 300 kg N/ha, resulting in a lower N use efficiency of the grass-clover N than for N applied in manure (Olesen et al., 2009). Both the N use efficiency and the cereal grain yields may be increased through better recycling of the grass-clover N, e.g. through biogas treatment of the grass-clover crops (Stinner et al., 2008).

The rotation effects of grass-clover could not be determined for oats due to the experimental design. For spring barley the effect of grass-clover in the rotation was a yield increase of 0 to 0.4 Mg DM/ha. This is less than for winter cereals, where the effect varied from 0.2 to 0.8 Mg DM/ha. The smallest effect was found at Jyndevad, probably due to increased organic matter turnover and higher rates of N leaching on this sandy soil. The larger effect of grass-clover in the rotation on winter cereals compared with spring cereals can be attributed to a shorter time (2 years) between grass-clover and winter cereals versus 3 years between grass-clover and spring barley in rotation O1 and O2. This indicates that the residual effect of grass-clover on grain yields only lasts a few years.

Catch crops gave no significant yield increase in winter cereals, although the estimated effects were all positive. However, it should be noted that the crop rotations with grass-clover (O1 and O2) only allows for a small proportion of catch crops in the rotation thus reducing the overall effect of having catch crops in the rotation. The estimated yield effects of catch crops in spring barley varied from 0.4 to 0.7 Mg DM/ha, and similar effects were obtained in spring oats (Tables 3 and 4). This is larger than the effect of including grass-clover as green manure in the crop rotation, but less than for application of manure.

Weeds were estimated to reduce crop yields for all crops and at all sites. The average amounts of weeds assessed as weed dry matter at anthesis in proportion of total above-ground bioomass across all treatments and years were 6.5, 3.7 and 6.3% at Jyndevad, Foulum and Flakkebjerg. This gives average yield reductions from weeds of 0.1 to 0.2 Mg/ha in winter cereals, 0.2 to 0.3 Mg/ha in spring barley and 0.2 to 0.6 Mg/ha in spring oats. These effects are considerably smaller than the beneficial effects of manure application, green manure crops and catch crops. This shows that the weed control in general has been sufficient and acceptable in the experiment. However, poor weed control can easily double weed pressure and also double the yield losses from this weed pressure.

Conclusions

Animal manure was the most important factor for increasing grain yield of cereal crops, but grass-clover and catch crop also contributed considerably to increasing yields. Yields were significantly reduced by weeds, and maintaining stable yields requires good weed control and prevention measures.

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References

Askegaard, M., Olesen, J.E., Kristensen, K. (2005): Nitrate leaching in organic arable crop rotations: Effects of location, manure and catch crop. Soil Use Manage. 21:181-188.

Olesen, J.E., Askegaard, M., Rasmussen, I.A. (2000): Design of an organic farming crop-rotation experiment. Acta Agric. Scand. B-S P. 50:13–21.

Olesen, J.E., Hansen, E.M., Askegaard, M., Rasmussen, I.A. (2007): The value of catch crops and organic manures for spring barley in organic farming. Field Crops Res. 100:168-178.

Olesen, J.E., Askegaard, M., Rasmussen, I.A. (2009): Winter cereal yields as affected by animal manure and green manure in organic arable farming. Europ. J. Agron. 30:119-128.

Stinner, W., Möller, K., Leithold,G. (2008): Effects of biogas digestion of clover/grass-leys, cover crops and crop residues on nitrogen cycle and crop yield in organic stockless farming systems. Europ. J. Agron. 29:125-134.