

Effects of organic matter input on soil microbial properties and crop yields in conventional and organic cropping systems

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Abstract

Unlike conventional cropping systems, which are characterised by targeted short-term fertility management, organic farming systems depend on long-term increase in soil fertility and promotion of soil biodiversity. This study sought to investigate long-term effects of organic matter inputs on various cropping systems in a 10-year-old experiment. Results show that in the long-term high C and N inputs enhance microbial activity. Microbial biomass N and the potential nitrification rate were higher in cropping systems based on green manure than in those reliant on inputs from animal manure and mineral fertilizer. Soil microbiological properties were affected by the individual crops in the rotation. The high microbial activity with increased organic matter inputs did not transform to enhanced crop productivity.

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 (Watson et al., 2002). The fertility building in organic cropping systems has consequences for soil biological properties, which subsequently may influence N and C flows and emissions, including greenhouse gases (Robertson et al., 2000; Mäder et al., 2002). The changes in organic matter input may affect crop yields and soil properties differently in different systems depending on mineral nutrient supply to the crops. These effects can only be properly studied in long-term experiments, where the fertility effects of various cropping systems are reflected in changes in soil properties and in crop responses. In this paper we explore the effects of different organic matter inputs on crop yields and soil microbiological properties in a 10-year old cropping system experiment in Denmark.

Materials and methods

A crop rotation experiment was initiated in 1996/97 at three sites in Denmark (Olesen et al., 2000), but only data from the site at Foulum is used in this paper (Table 1). Foulum is located in Central Jutland on a loamy sand with an annual rainfall of 704

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mm. During the period 1997 to 2004 the experimental factors were 1) proportion of N₂-fixing crops in the crop rotation, 2) with (+CC) and without (-CC) catch crop, and 3) with (+M) and without (-M) animal manure. Two crop rotations (O2 and O4) with different proportions of cereals and nitrogen fixing crops in a four-year rotation were tested (Table 1). All crops in all rotations are represented every year in two replicates (blocks). The plots receiving manure were supplied with anaerobically stored slurry at rates where the NH₄-N amount corresponded to 40% of the N demand of the specific rotation based on a Danish national standard (Plantedirektoratet, 1997). The grass-clover was used solely as a green manure crop, and the cuttings were left on the ground. All straw was left in the field.

From 2005 the design was changed to include a conventional cropping system (C4) with a crop rotation similar to the O4 rotation (Table 1). Conventional treatments (C4) replaced the previous -CC/-M treatments in O2 and O4 such that O2/-CC/-M was converted to C4/+CC and O4/-CC/-M was converted to C4/-CC. The crops in C4 received mineral fertiliser at recommended rates. A mixture of legume and non-legumes were used for the catch crops in O2 and O4, whereas non-legumes were used in the C4 catch crop treatment. From 2001 the cuttings in grass-clover in O2/+M was no longer mulched, but removed from the field. Manure application is based on the principles of recirculation, where nutrients in the cuts from the grass-clover are processed by anaerobic digestion and redistributed to the row crop and cereals in the rotation. In O4/+M treatments the manure application is based on import from conventional farms. Weeds were controlled by mechanical means in O2 and O4, whereas pesticides were used at recommended rates in C4 to control weeds, pests and diseases.

Table. 1: Structure of the crop rotations.

	Crop rotation	O2	O4	C4
1 st course 1997-2000	1	S. barley:ley	Spring oat ^{CC}	
	2	Grass-clover	Winter wheat ^{CC}	
	3	Winter wheat ^{CC}	Winter cereal ^{CC,1}	
	4	Pea/barley ^{CC}	Pea/barley ^{CC}	
2 nd course 2001-2004	1	S. barley:ley	Winter wheat ^{CC}	
	2	Grass-clover	Spring oat ^{CC}	
	3	Winter wheat ^{CC}	S. barley ^{CC}	
	4	Lupin/barley ^{CC}	Lupin	
3 rd course 2005-2008	1	S. barley:ley	S. barley ^{CC}	S. barley ^{CC}
	2	Grass-clover	Faba bean ^{CC,2}	Faba bean ^{CC,2}
	3	Potato	Potato	Potato
	4	Winter wheat ^{CC,3}	Winter wheat ^{CC,3}	Winter wheat ^{CC,3}

^{CC} Catch crop in the +CC-treatments, ¹ Triticale in 1999 and 2000, ² Pea/barley in 2005, ³ S. oats in 2005.

Grain yields were measured at maturity using a combine harvester. Samples of total above-ground biomass in the grass-clover were taken in 1 m² sample areas in each plot at each cut. To determine total crop production, samples of total above-ground biomass were taken in 1 m² sample areas in each plot 1-2 weeks before maturity. Similar samples of total above-ground biomass were taken about 1 November to measure the above-ground biomass of catch crops and weeds. Total N in the grain and plant samples were determined on finely milled samples from each plot by the

Dumas method. Carbon content in plants was estimated under the assumption of 46% C content in plant DM biomass. Soil organic C and N were determined by dry combustion. Microbial biomass was determined by the chloroform fumigation incubation technique (Joergensen and Brookes, 1990). Nitrification potential was assessed using the method described by Hart et al., (1994).

Results

There were higher C and N inputs from aboveground material in the organic compared to the conventional systems, in particular affected by the catch crop (CC) treatment (Table 2). The organic system O2/+CC received significant C and N inputs from grass-clover and O4/+CC from crop residues and catch crops. This was reflected in a higher soil organic C content in the organic compared to the conventional treatments (Table 3). Microbial biomass N and nitrifier activity was highest in the O2/+CC and lowest in the conventional system (Table 3). The microbial population and activity, which increased with organic inputs in plots that will have spring barley in 2008, but showed no clear trend in the winter wheat plots. Annual grain yields were consistently higher in conventional compared to organic systems (Table 4). Grain yields obtained in the O4/+CC were comparable with yields from the O2/+CC. The low yields obtained for spring oats in the conventional system in 2005 were due to crop lodging.

Table 2. Annual C and N inputs in organic matter of manure and above-ground plant material (1997- 2006).

	Source	C4/-CC	O4/-CC	O4/+CC	O2/+CC
C input (Mg DM/ha/yr)	Manure	0.0	0.3	0.3	0.2
	Grass-clover	0.0	0.0	0.0	1.6
	Crop residues	2.1	2.4	2.9	2.4
	Catch crops	0.2	0.2	1.0	0.3
	Total	2.3	2.9	4.2	4.5
N inputs (kg N/ha/yr)	Manure	0	18	18	15
	Grass-clover	0	0	0	95
	Crop residues	42	40	61	44
	Catch crops	10	9	58	16
	Total	52	66	137	170

Table 3. Soil biological and chemical properties (\pm S.E; n =2)

Soil Parameter	2008 crop	Treatment			
		C4 /-CC	O4/-CC	O4/+CC	O2/+CC
Organic C (%)	S. barley	1.95	2.10	2.09	2.28
	W. wheat	1.91	2.29	2.00	2.39
Microbial biomass N (μ g N / g soil)	S. barley	32.1(2.3)	36.3(2.3)	36.0(4.0)	47.2 (0.8)
	W. wheat	27.2 (2.2)	32.7(1.3)	27.2*	29.2 (3.3)
Potential Nitrification (nmol NO ₃ / g soil / h)	S. barley	10.6(0.3)	13.9(0.01)	15.5(1.6)	16.6(0.4)
	W. wheat	12.3(1.7)	16.3(1.9)	15.1(0.2)	17.9(0.2)

Discussion

The results suggest that increased microbial activity follows increased annual C and N inputs in cropping systems. This finding agrees with Raupp (1995), who reported higher microbial biomass in organic compared to conventionally managed soils. Catch crops significantly increase soil organic matter levels (Olesen et al., 2007), thus microbial activity and grain yield were as expected lower in organic system without catch crops. In line with the observations made by Acosta-Martinez et al., (2004), microbiological parameters, unlike organic C, were effected by crop type. The lower microbial population after the potato crop that preceded winter wheat suggests that potatoes had a negative effect on soil rhizosphere microbial populations. The generally higher nitrifier activity could be due to high residual N as the 2007 potato crop was affected by disease. Increased organic matter inputs enhanced microbiological properties, but did not necessarily translate to improved crop productivity. This is inevitable in organic systems where plant nutrient demand is rarely in synchrony with nutrient availability (Watson et al., 2002).

Table 4. Dry matter grain yields Mg DM ha⁻¹ (\pm SE; *n* = 6)

Crop	Year	Treatment			
		C4/-CC	O4/-CC	O4/+CC	O2/+CC
S. oat	2005	4.12	5.11	5.42	5.27
W. wheat	2006	7.05	5.19	6.08	6.16
	2007	6.86	3.50	3.32	4.00
S. barley	2005	6.25	4.92	5.19	4.86
	2006	5.74	4.38	5.14	4.77
	2007	4.64	3.13	4.53	4.51
Mean		5.78 (0.41)	4.37 (0.3)	4.95 (0.32)	4.93 (0.25)

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