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Soil quality and crop productivity as affected by different soil management systems in organic agriculture

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Abstract

Compost prepared on-farm based on plant residues may be an alternative for manure from extensive conventional livestock systems. In a multi-year field trial, we compared two soil management strategies: 1) farm compost application combined with reduced tillage and 2) animal manure incorporated by conventional mouldboard ploughing. Benefits for crop performance of both systems depended on the crop used in the rotation and the weather. A wet spring season caused the spring barley crop in the reduced tillage system to fail. The system showed a good potato yield due to a better youth growth, however. After one 4-year rotation, soil organic carbon content and pH of the upper 0-10 cm soil layer was ca 20% and 0.5 unit higher for farm compost compared to the farmyard manure treatment. The combination of compost application and reduced tillage proved to be a promising soil management strategy.

Introduction

The use of manure from conventional livestock systems is authorised in organic agriculture due to a lack of animal manure from organic livestock farms. On-farm prepared compost, which mainly consists of plant residues, may be an alternative for animal manure. Compost can be easily applied in a reduced tillage system. Reduced tillage systems are favourable for soil quality but are not always easy to apply in organic agriculture (Peigné et al. 2007). One of the constraints may be the incorporation of a straw-rich farmyard manure. We conducted a multi-year field trial to compare soil management strategies (tillage and fertilisation) with regard to their effect on crop performance and soil quality. Two soil management systems were assessed. Farm compost application was combined with reduced tillage by non-inversion tillage using a chisel plough. In contrast, animal manure was incorporated by conventional tillage with a mouldboard plough.

Materials and methods

This soil management trial took place on a sandy loam soil on two adjacent fields of the Institute for Agricultural and Fisheries Research (ILVO) located in Flanders, Belgium. On one field the trial started in 2005. On the other field the trial was repeated with a time delay of one year (2006 start). Prior to starting the trial, the fields underwent a 2-year conversion period to organic agriculture. During that time a grass-clover ley was installed as green manure crop and was regularly mulched. The crop rotation used was a 4-year cycle of maize (*Zea mays ssp mays*) - potatoes (*Solanum tuberosum*) - spring barley (*Hordeum vulgare*) - red clover (*Trifolium pratense*) (Table 1). Winter rye (*Secale cereale*) was sown as a green manure after maize; yellow mustard (*Sinapis alba*) was sown after potatoes. On the first field, red clover was sown in summer 2007 after spring barley. On the second field, red clover was sown in spring 2009. Five soil management treatments were compared, each of which was a specific combination of a tillage practice and a fertilisation type. The first combination was reduced tillage (RT) by non-inversion tillage with a chisel plough (Actisol) up to a depth comparable to the ploughing depth, together with farm compost application. Farm compost was applied in either a single dose (FC) or double dose (2xFC). Farm compost was produced at ILVO in a windrow composting system using an equilibrated, predominantly vegetative feedstock mix. Conventional tillage (CT) with a mouldboard plough was combined with three different types of fertilisation, which all included animal manure: farmyard manure (FYM), cattle slurry (S) and slurry plus municipal waste compost (S+MWC). Organic matter input by fertilisation was equalised for the RT-FC, CT-FYM and CT-S+MWC treatments. The treatments were arranged in strips of 15 by 50 or 100 m; the dimensions of the strip varied according to the treatment. In those strips, four plots (1 m^2) at a preset location were used for soil sampling (0-10 and 10-30 cm). The soil quality parameters total organic carbon content (TOC), total N content (Ntot), pH-KCl and plant available nutrients (extractable with ammonium-lactate) were measured. Crop yield was determined per treatment in

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four replicates on plots scattered over the respective strip. Differences between treatments with regard to yield were assessed by the Scheffe method for both growing seasons separately. 'Field' was considered as an additional factor in the data analysis with regard to the soil quality parameters. Differences between treatments for soil parameters were assessed by the Dunnett ($P<0.05$) method with CT-FYM as the reference treatment and for both soil layers separately.

TOC content was measured on oven-dried (70 °C) soil samples by dry combustion at 1050 °C with a Skalar Primacs SLC TOC-analyser according to ISO 10694. For soils with pH-KCl > 6.5, inorganic carbon was measured separately; none of the samples had inorganic carbon levels higher than the limit of quantification. pH was measured potentiometrically in a 1M KCl solution (1:5 v/v) according to ISO 10390. Ntot content was determined by dry combustion (Dumas principle) with a thermo flash 4000 according to ISO 13878. Plant available nutrients (P, Ca, Mg, K) were determined by shaking 5 g air-dried soil in 100 ml ammonium lactate for four hours (Egnèr et al., 1960) and were measured using a CCD simultaneous ICP-OES (VISTA-PRO, Varian, Palo Alto, CA).

Table 1: Arrangement of the crops in the rotation of the two adjacent fields

year	field 1	field 2
2005	maize	
2006	potatoes	maize
2007	spring barley	potatoes
2008	red clover	spring barley
2009		red clover

Results

Final soil quality assessment

Compost application (either farm compost or municipal waste compost) clearly positively affected TOC and pH-KCl in the 0-10 cm soil layer, irrespective of the tillage system (Table 2). Steel et al. (2012) reported that a pH increase is an important short-term effect of farm compost application, irrespective of the feedstock materials used in the compost. Increases of Ntot, plant available P and Ca in the 0-10 cm soil layer were only observed for farm compost application under RT. The deep incorporation of municipal waste compost by ploughing also resulted in a TOC increase in the 10-30 cm soil layer. A double compost dose (2xFC) led to K enrichment in the 10-30 cm soil layer. This increase is probably caused by leaching because of the superficial incorporation of the compost.

Crop results

In 2005, no yield differences between treatments were observed for maize. Averaged over the treatments, maize yielded 18.9 t dry matter ha^{-1}. In 2006 maize yield was lower for the RT-2xFC treatment (13.2 t dry matter ha^{-1}) compared to all other treatments (on average 16.7 t dry matter ha^{-1}) due to a lower plant density related to bird damage in the crop youth stage. The potato crop showed better youth growth in the RT system with farm compost than in the ploughed treatments with animal manure. In 2006, this resulted in a higher potato yield for both farm compost treatments (Willekens et al. 2008). Spring barley yield in 2007 was approximately 0.5 t ha^{-1} lower for the RT-FC treatment compared to the other treatments (3.5-3.6 t ha^{-1}) except the CT-S+MWC treatment. In 2008, a crop failure occurred for the RT practice. Due to a wet spring season, deep RT was omitted. This led to serious weed-related problems during the crop youth stage. The highest yield was registered in the CT-FYM treatment, approximately 4 t ha^{-1}. In 2008, the dry matter yield (4 successive cuts) in the RT-2xFC treatment exceeded the yield in some of the other treatments, whereas in 2009, the highest dry matter yield (2 successive cuts) was registered for CT practice with animal manure.

Table 2: Final soil quality parameter values for 5 soil management treatments

		0-10 cm soil layer				
SOIL		RT		CT		
MANAGEMENT		FC	2xFC	FYM	S	S+MWC
TOC	%	1.1 *	1.2 *	0.9	1.0	1.1 *
Ntot	%	0.10 *	0.11 *	0.09	0.09	0.09
pH-KCl		5.4 *	5.6 *	4.9	5.2	5.3 *
P	mg / 100 g	23.3 *	24.1 *	17.3	17.3	17.6
Ca	mg / 100 g	74.5 *	82.7 *	57.7	73.6	71.8
K	mg / 100 g	18.3	24.8	14.3	14.0	15.5
Mg	mg / 100 g	11.2	12.9	10.1	10.3	10.2
		10-30 cm soil layer				
SOIL		RT		CT		
MANAGEMENT		FC	2xFC	FYM	S	S+MWC
TOC	%	0.9	0.9	0.8	0.9	1.0 *
Ntot	%	0.08	0.08	0.08	0.08	0.09
pH-KCl		5.3	5.4	5.0	5.2	5.3
P	mg / 100 g	24.0	23.8	20.3	19.9	19.9
Ca	mg / 100 g	71.6	77.5	62.3	85.8 *	75.6
K	mg / 100 g	12.4	17.2 *	13.5	11.0 *	12.0
Mg	mg / 100 g	10.5	11.1	10.2	9.3	9.6

*significantly different from FYM value, Dunnett, P<0.05

Discussion

With regard to soil quality, a reduced tillage practice in combination with compost application seemed to be favourable for soil quality of the surface layer in the short term. With regard to crop productivity, an effect of soil management strategy was less clear and depended on seasonal variation of the field situation. More insight is needed about performing reduced or non-inversion tillage techniques in order to optimise seed-plant bed conditions. Vegetative compost may partly replace animal manure input in organic cropping systems. Compost is suitable for a reduced tillage system, as appeared in these experiments. Animal manure can also be composted before application (Berner et al. 2008). Reduced tillage systems lower the need for fuel and labour and compost fertilisation is important for closing nutrient cycles. To encourage the use of FC in combination with RT practices, more information is needed about how to prepare low-cost, high-quality compost on farm.

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