European Journal of Agronomy 94 (2018) 79–88

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Soil carbon varies between different organic and conventional management schemes in arable agriculture

Teng Hu*, Peter Sørensen, Jørgen Eivind Olesen

Department of Agroecology, Aarhus University, Blichers Allé 20, Tjele, DK 8830, Denmark

ARTICLE INFO

Keywords:
Green manure
Catch crops
Animal manure
Organic farming
Soil organic carbon

ABSTRACT

The effects of organic versus conventional farming systems on changes in soil organic carbon (SOC) has long been debated. The effects of such comparisons may depend considerably on the design of the respective systems and climate and soil conditions under which they are performed. Here, we compare a range of arable organic and conventional crop systems at three sites (Jyndevad, Foulum and Flakkebjerg) in Denmark through long-term experiments initiated in 1997. The experimental treatments in the organic farming systems included use of whole-year green manure crops, catch crops and animal manure (as cattle, pig or digested slurry). Data on plant residues and animal manure were used to estimate C inputs to the soil. This was compared with measured changes in topsoil (0–25 cm) SOC content over 4–8 years.

During 1997–2004, green manure, catch crops and animal manure enhanced estimated C input by 0.9, 1.0 and 0.7 Mg C ha^{-1} yr^{-1} respectively, across all locations. Based on measured SOC changes, green manure enhanced SOC by 0.4 Mg C ha^{-1} yr^{-1} and catch crops by 0.2 Mg C ha^{-1} yr^{-1}, while animal manure by insignificantly 0.1 Mg C ha^{-1} yr^{-1}. After 2005, advantages of using green manure (grass-clover) on SOC change disappeared, because cuttings of the grass-clover was removed whereas before 2005 they were mulched in the field, albeit there was still a small extra estimated C input of 0.2 Mg C ha^{-1} yr^{-1}. An estimated higher C input of 0.7 Mg C ha^{-1} yr^{-1} with catch crops did not result in significant increase in measured topsoil SOC.

From 2005–2008, the first 4 years of comparison between organic and conventional farming at all three sites, organic farming with animal manure had 0.3 Mg C ha^{-1} yr^{-1} higher estimated C input, but SOC measurements showed that conventional farming accumulated 0.4 Mg C ha^{-1} yr^{-1} more SOC than organic farming. At Foulum from 2005 to 2012, organic farming with animal manure had 0.7 Mg C ha^{-1} yr^{-1} more input, and topsoil SOC measurements showed a higher accumulation of 0.4 Mg C ha^{-1} yr^{-1} in organic compared with conventional farming.

Regressions of changes in topsoil SOC against estimated C inputs showed that 10–20% of C inputs were retained in topsoil SOC over the experimental period. There was no clear indication that belowground C input contributed more to SOC than aboveground C inputs. Despite consistently higher estimated C inputs in organic versus conventional systems, we were not able to detect consistent differences in measured SOC between the systems.

1. Introduction

Globally, soil is one of the most important terrestrial stores of carbon (C) (Davidson et al., 2000; Lal, 2008; Lehmann and Kleber, 2015); however, agricultural soil C is undergoing substantial change due to both environmental conditions and management effects (Janzen et al., 1997; West and Post, 2002; Crowther et al., 2016). Soil organic C (SOC) is an essential indicator of soil fertility and soil quality (Susanne and Michelle, 1998; Al-Kaisi et al., 2005; Huang et al., 2007; Merante et al., 2017). Properly managing SOC may not only bring benefit to productivity and environment, but also mitigate negative effects of extreme events, like droughts, by improving soil hydraulic properties (Gomiero et al., 2011). Enhancing SOC can contribute to reducing net agricultural greenhouse gas emissions, not only by storing C in soils, but also facilitating changes in soil structure that in some cases may reduce N_2O emissions (Mutegi et al., 2010; Powlson et al., 2011). SOC is also associated with higher contents of nutrients such as nitrogen, phosphorus and sulphur (Kirkby et al., 2011), and managing SOC is therefore also closely linked to soil nutrient management, in particular in organic farming (Watson et al., 2002; Gomiero et al., 2011; Reganold

---

* Corresponding author.
E-mail address: huteng@agro.au.dk (T. Hu).

https://doi.org/10.1016/j.eja.2018.01.010
Received 20 October 2017; Received in revised form 5 January 2018; Accepted 11 January 2018

Table 1
Structure of the organic (O) and conventional (C) crop rotations at three locations: JY = Jyndevad, FO = Foulum, FL = Flakkebjerg.

Crop rotations	O1			O2			O4			C4		
Cycles	Crop	M[1]	CC[2]	Crop	M[1]	CC[2]	Crop	M[1]	CC[2]	Crop	M[1]	CC[2]
1st cycle 1997–2000	S. barley:ley	50		S. barley:ley	50		S. oat	40	+[5]			
	Grass-clover	0		Grass-clover	0		W. wheat	70	+[5]			
	S. wheat	50	+[3]	W. wheat	50	+[3]	W. cereal	70	+[5]			
	Lupin	0	+[4]	Pea/barley	0	+[4]	Pea/barley	0	+[4]			
2nd cycle 2001–2004	S. barley:ley	50		S. barley:ley	50		W. wheat	50	+[4]			
	Grass-clover	0		Grass-clover	0		S. oat	50	+[4]			
	S. oat	30	+[3]	W. cereal	50	+[3]	S. barley	50	+[3]			
	Pea/barley	0	+[4]	Lupin	0	+[4]	Lupin	0				
Locations	JY			JY, FO, FL			FO, FL					
3rd cycle 2005–2009	Discontinued			S. barley:ley	60		S. barley	60	+[4]	S. barley	130	+[3]
				Grass-clover	0		F. bean	0	+[4]	F. bean	0	+[3]
				Potato	100		Potato	110		Potato	140	
				W. wheat	100	+[4]	W. wheat	110	+[4]	W. wheat	165	+[3]
Locations				JY, FO, FL			JY, FO, FL			JY, FO, FL		
4th cycle 2010–2012				S. barley:ley	60		S. barley	60	+[4]	S. barley	120	+[3]
				Lucerne, 1st	0		Hemp	90		Hemp	125	
				Lucerne, 2nd	0		Peas/barley	0	+[4]	Pea/barley	0	+[3]
				S. wheat	100	+[4]	S. wheat	100	+[4]	S. wheat	110	+[3]
				Potato	100	+[4]	Potato	100	+[4]	Potato	140	+[3]
Locations				FO			FO			FO		

[1] M: Manure application target rates in +M treatments. Unit: kg NH_4-N ha^{-1} in 1st and 2nd cycles and kg total-N ha^{-1} in 3rd cycle. Inorganic fertilizer rates are shown as target mineral N in kg N ha^{-1}. [2] CC: Crops succeeded by catch crops in +CC treatments. [3] Monocultures or mixtures of non-N_2-fixing catch crop. [4] Mixtures of N_2-fixing and non-N_2-fixing catch crop. [5] White clover.

and Wachter, 2016).

SOC is primarily managed through soil C inputs, since tillage intensity has shown to have little effect on total SOC storage, although the vertical profile of C concentration is affected by tillage (Powlson et al., 2014). Enhancing SOC thus requires that additional C is added to the soil, which may be achieved by enhancing crop productivity to achieve a higher amount of crop residues or by retaining a larger proportion of the residues in the cropping systems (Powlson et al., 2011). Organic farming, as an approach to environmentally friendly agriculture practice (Reganold and Wachter, 2016), emphasizes increasing SOC and enhancing nutrient cycling through measures such as growing green manure and catch crops, and applying manure (Olesen et al., 2007), which provides additional sources of C inputs besides residues from arable crops. Organic farming has been demonstrated to have higher total C input (Gattinger et al., 2013) and topsoil SOC stocks (Gomiero et al., 2011; Gattinger et al., 2012; Tuomisto et al., 2012) than conventional farming. This is partly a consequence of higher external C input in organic farming, e.g. through animal manure and compost. Compared to conventional farming, organic farming has been criticised for lower crop yields that may lead to lower C inputs (Connor, 2008; Leifeld, 2012; Seufert et al., 2012) and less net transfer of C to the soil from photosynthesis of the crops being grown (Leifeld et al., 2013). However, crops vary greatly in their C inputs from above- and belowground crop residues, and in particular, belowground C inputs are difficult to quantify. Recent research strongly suggests that belowground C input is independent of aboveground biomass for many crop species (Chirinda et al., 2012; Taghizadeh-Toosi et al., 2016; Hu et al., 2018). Additionally, higher root biomass C input of cereals in organic farming compared to conventional systems indicates that belowground C input in organic farming systems may be underestimated (Chirinda et al., 2012). The inputs of C from roots and rhizodeposition may be of particular importance for SOC, since studies have shown that these sources of C may be better retained in soils than C from aboveground crop residues (Rasse et al., 2005; Kätterer et al., 2011; Berti et al., 2016).

There is thus a need to improve the understanding of how the management measures in organic farming contribute to C inputs and retention in soils. Data from long-term experiments with variation in cropping system design and crop management may provide valuable insights by providing information on C inputs and on changes in SOC storage. Such long-term experiments were initiated at three sites in Denmark in 1997 (Olesen et al., 2000), and they thus provide an opportunity to reveal how different components of organic farming systems contribute to soil C inputs and to changes in SOC. The aim of this study was to assess how different components from conventional and organic cropping systems in long-term experiments in Denmark contribute to changes in SOC. For this, we hypothesize: 1) Green manure crops, catch crops and manure add significant amounts of C to the soil that also contribute to measureable changes in SOC; 2) Organic farming can provide higher C input than conventional farming, and this will result in higher SOC of organic compared with conventional farming; 3) Belowground plant inputs contribute to SOC through higher retention of the added organic C than for aboveground parts.

2. Materials and methods

2.1. Field sites

Changes in soil C monitored in long-term experiments on organic and conventional cropping systems at three sites in Denmark, varying in soil type and climate, i.e. Jyndevad (54°54′N, 09°08′E), Foulum (56°30′N, 09°35′E) and Flakkebjerg (55°20′N, 11°23′E) were used for this study. Jyndevad is located in Southern Jutland on a coarse sandy soil (Gleyic Podzol), Foulum is situated in Central Jutland on loamy sand soil (Mollic Luvisol), and Flakkebjerg is placed in Western Zealand on sandy loam soil (Glossic Phaeozem) (classification according to WRB and FAO). In the topsoil (0–25 cm), the clay content at Jyndevad, Foulum and Flakkebjerg were 45, 88 and 155 g kg^{-1}, respectively. The