

Soil organic matter balances in organic versus conventional farming—modelling in field experiments and regional upscaling for cropland in Germany

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Abstract The question of whether organic farming leads to higher soil organic matter (SOM) levels in arable soils compared with conventional farming is an ongoing debate. Building on several studies reported in the literature, we hypothesize that the impact on SOM levels is not an intrinsic characteristic of any farming system but is the result of the actual structure

of the farming system, in particular, the composition and management of crop rotations, and the availability and utilization of organic manure. The SOM balances for organic versus conventional farming in Germany are compared by considering data on the structure of organic and conventional farming systems from agricultural census reports and then applying the SOM

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balance model HU-MOD. Preliminary testing confirmed the applicability of the model using a survey on soil organic carbon (SOC) change and SOM balances in four long-term field experiments in Germany and Switzerland and found that more positive SOM balances coincided with higher SOC levels. We therefore conclude that, where the SOM supply level of organic farming systems is higher than in conventional management, a shift from conventional to organic agriculture would increase SOM levels. Upscaling using agricultural census data in Germany, we found that SOM balances of organic farming were more positive than for conventional farming in the scenarios without consideration of animal manure application, but SOM balances for the two systems were not different where animal manure application rates were assumed to be at the current average rate for all cropped land. However, in fact, animal manure availability and application shows strong regional variations, and it is likely that this would affect the mean cropland SOM balance if it were possible to calculate it based on such spatially disaggregated data. We confirm the applicability of simple SOM balance models to compare the impact of farming systems and cropland structures on SOC levels. More work is needed to develop data inputs at a sufficient spatial and structural resolution to support more detailed evaluation.

Keywords Soil organic matter · Farming systems · Sustainability · Environmental impact assessment

Introduction

The potential contribution of agriculture to carbon (C) sequestration is considerable (Lal 2004) even though the carbon sink function of agricultural soils is finite and temporally limited (Smith 2004). Within agricultural systems, it has been suggested that conversion to organic farming would be one appropriate and effective measure to promote C sequestration due to enhanced soil organic matter (SOM) levels compared with conventional farming (Freibauer et al. 2004; Lal 2006).

In field surveys, a number of studies (e.g., Foissner 1992; Munro et al. 2002; Piorr and Werner 1998; Pulleman et al. 2003; Reganold 1988) have identified higher SOM levels as a characteristic property of organically managed compared with conventionally managed soils. These observations are also supported by results

from long-term field experiments (e.g., Fließbach et al. 2007; Hepperly et al. 2006; Mazzoncini et al. 2010). Using the CENTURY model (Parton et al. 1987), Foereid and Høgh-Jensen (2004) calculated an increase in soil organic carbon (SOC) of 10–40 g C m⁻² year⁻¹ over a period of 50 years after conversion of arable land from conventional to organic farming practices. However, higher SOM levels are not always found in organic compared with conventional farming systems (van Diepeningen et al. 2006; Gosling and Shepherd 2005; Marinari et al. 2006). Recently, Kirchmann and Bergstroem (2008) concluded that organic farming will lead to a loss of soil organic matter compared with intensive crop production, at least where comparable crop yield levels are assumed as basic condition.

Consequently, it is necessary to carry out appraisals at farming system scale and use a method for the quantitative analysis of actual SOM balances, as suggested by Leifeld and Fuhrer (2010) and Shepherd et al. (2002). Both papers conclude that management impact on soil organic matter is likely to be dependent on actual organic matter input and not on farming system labels. We therefore hypothesize that the impact on SOM levels is not an intrinsic characteristic of any farming system but is the result of the actual structure of the farming system, in particular, the composition and management of crop rotations, and the availability and utilization of organic manures. Our aim is therefore to contribute to this discussion by (1) analyzing the impact of specific organic versus conventional farming systems on SOM levels in four long-term field experiments in Germany and Switzerland with a simple SOM balance model, and (2) scaling-up the results with scenario calculations based on data on farm system structures on organic and conventional farming in Germany obtained from agricultural censuses.

Materials and methods

Evaluation of the HU-MOD model in the comparison of organic and conventional farming systems

Four long-term field experiments, three in Germany and one in Switzerland, were included in the model evaluation. Relevant site and management data are given in Tables 1 and 2, and more detailed descriptions of the experiments are provided by Debruck (2003), Deike et al. (2008), Mäder et al. (2006), and

Table 1 Overview of long-term field experiments (LTFE) included

Long-term field experiment (ID), institution	Location	Starting year	Site	Survey period ^a	Data availability
DOK trial (DOK), Forschungsinstitut für Biologischen Landbau FIBL and Agroscope Reckenholz-Tänikon ART	Therwil (Baselbiet, Switzerland)	1978	Mean values: annual temp. 9.5 °C, annual precip. 792 mm, soil: loamy silt	1978–2005	Soil: annual plot data on Corg and Nt contents, with single missing years Yields: main and side products of all crops recorded for each plot and year; DM and N contents not recorded fertilization: type and amount of fertilizer recorded for each treatment; N input recorded.
Farming systems trial (BL), Martin-Luther-Universität Halle-Wittenberg	Bad Lauchstädt (Saxony-Anhalt, Germany)	1998	Mean values: annual temp. 8.7 °C, annual precip. 484 mm, soil: loamy silt	1998–2003	Soil: annual plot data on Corg and Nt contents Yields: main and side products of all crops recorded for each plot and year; DM and N contents not recorded Fertilization: type and amount of fertilizer recorded for each treatment; N input recorded
KA trial (BN), Regional Institute for Agriculture, Forestry and Horticulture Saxony-Anhalt	Bernburg (Saxony-Anhalt, Germany)	1994	Mean values: annual temp. 9.2 °C, annual precip. 469 mm, soil: loamy silt	1994–2005	Soil: tetra-annual plot data on Corg and Nt contents Yields: main and side products of all crops recorded for each plot and year; DM and N contents not recorded fertilization: type and amount of fertilizer recorded for each treatment; N input recorded.
Farming systems trial (DDF), Julius-Kühn-Institut	Dahnsdorf (Brandenburg, Germany)	1996	Mean values: annual temp. 8.7 °C, annual precip. 510 mm, soil: silty sand	2000–2006	Soil: plot data on Corg contents for the year 2000 Yields: only main products of cash crops and fodder main crops recorded for each plot and year; DM and N contents not recorded fertilization: type and amount of fertilizer recorded for each treatment.

^a Denoted survey periods apply to the calculation of SOCTrend and SONtrend, and to SOM balance calculation

Reinicke et al. (2003). Two of the four long-term field experiments are located in eastern Germany on silt soils with a high potential yield level (BL, BN). One other experiment is located in eastern Germany, too, but on sand soils (DDF). The fourth experiment (DOK) is located on loam soils near Bale (Switzerland). All of these field experiments compare organic versus conventional farming. Due to limitations in capacity, we evaluated only some treatments from each experiment,

where these treatments were considered by the site managers to best reflect typical farming practice under organic and conventional management.

For each experimental treatment included, SOC change in the topsoil was calculated for the survey period using data provided for each site, including additional data from a comparative survey carried out in all experiments in Spring 2006. SOC was usually analyzed according to ISO 10694 (1995) in all experiments.

Table 2 Description of LTFE treatments included

LTFE (ID)	Included treatments (original ID)	Farming system (treatment ID in this survey)	Fertilization	Crop rotation (proportion of crop groups in %)				
				Perennial legume	Grain legume	Cereals	Row crops	Cover crops
DOK	M	CON-MIN	MIN					
	D2	BIODYN	CFYM	28.6	14.3	28.6	28.6	42.9 ^a
	O2	ORG-MF	FYM, SL					
BL	K2	CON-MF	FYM, SL, MIN					
	Org221	ORG-MF	FYM	16.7	16.7	50.0	16.7	16.7 ^a
	Int221	CON-MF	MIN, FYM					
	Org211	ORG-SFL	GM+S	16.7	16.7	50.0	16.7	16.7 ^a
BN	Int211	CON-SFL	MIN, GM+S					
	a1b1	CON-SFC	MIN, S+CC	0	12.5	62.5	25	0 ^a
	a2b1	ORG-SFC	S+CC	0	25	62.5	12.5	0 ^a
DDF	a3b1	ORG-MF	FYM	25	0	62.5	12.5	0 ^a
	BS2	CON-MF	MIN, FYM	16.7	0	83.3	0.0	16.7 ^a
	BS3	ORG-MF	FYM	33.4	0	50.0	16.7	16.7 ^a

Farming systems: *ORG* organic farming, *CON* conventional farming, *BIODYN* biodynamic farming, *MIN* artificial system with harvested perennial legumes but mineral fertilization only, *MF* mixed farming (with cattle), *SFL* stockless farming with rotational lay in crop rotation, *SFC* stockless cash crop farming; fertilization: *MIN* mineral fertilizer, *FYM* farmyard manure, *CFYM* composted farmyard manure, *SL* cattle slurry, *GM+S* perennial legumes as main green manure plus straw, *S+CC* straw and cover crops as green manure

^a Values for cover crops relate to the proportion of years with cover cropping in complete crop rotations

Furthermore, we calculated SOM balances for all treatments using the SOM balance model HU-MOD (Brock et al. 2012). Briefly, the balance is calculated as the sum of management-induced SOM loss (negative) and SOM supply (positive). Soil organic matter loss in HU-MOD is calculated by estimating the contribution of soil organic nitrogen (N) to crop nutrition, considering the supply by other pools (e.g., recently added organic fertilizers) and rates of mineralization stimulated by cultivation operations. Constitutively, SOC loss is calculated from SON loss assuming a default soil C/N ratio of 11.6. SOM supply is estimated based on organic inputs in plant biomass and organic fertilizers, taking account of organic matter losses as a result of rapid turnover of fresh OM additions. To run the model, the minimum data required are information on crop type together with the type and amount of fertilizer used in each year in the assessment period. For better calibration, the yields of main and side products (e.g., grain and straw) can be used as inputs. Side product yields and yield amounts of fodder crops were not available for all experiments. Data availability for all experiments is shown in Table 1.

Regression analysis was used to relate the calculated SOM balances to the measured SOC change between

treatments for each experiment with SOM balance as the driving variable (x) and SOC change as the dependent variable (y). The impact of site-specific factors are not fully recognized in HU-MOD, hence the regression coefficient (b) varies with site; the coefficient of determination (r^2) was considered as the key assessment parameter. The results are then interpreted on a three-step ordinal scale (positive–none–negative deviation of impact on SOC in scenario comparison; Brock et al. 2012). The advantages and limitations of the model will be addressed in the discussion.

SOM balances for cropland in Germany

SOM balances for conventional versus organic farming in Germany were then calculated using HU-MOD, applying three different scenarios that differ in complexity with regard to the data used as data inputs to the model. All the input values estimated and then applied in each scenario are shown in Table 4.

Scenario A is a pure cropland balance based on a new survey of the structure of agricultural production in Germany by BLE (2012). These data are comprised of absolute organic and conventional cropland area for

all agricultural crops, respectively, but there are no data on livestock and fertilization. As the applied SOM balance model requires input data on mineral N supply (Brock et al. 2012), we applied an estimated mean application of $100 \text{ kg N ha}^{-1} \text{ year}^{-1}$ for conventional cropland based on a nitrogen balance survey carried out for Germany by Panten et al. (2009).

Scenario B additionally includes data on straw incorporation and the use of catch crops. As the BLE survey does not include data on catch crop area, straw yield, or incorporation, we estimated these parameters from Statistisches Bundesamt (2011) for catch crop area and IFEU (2008) on straw removal. Both sources provide average values for German cropland, without regional differentiation or differentiation according to the farming system.

Finally, scenario C includes additional input data on animal manure application that was calculated from farming-system-related data of BMELV (2007) on livestock numbers on organic and conventional farms, and in addition, average data for manure application for both grassland and cropland in Germany by Statistisches Bundesamt (2011).

Results

Model evaluation in field experiments

The SOC changes indicated both increases and decreases in SOC in the experimental treatments over the period of the survey (Table 3). In the BL experiment, the effect of different cropping system structure types was stronger than the impact of farming systems. SOC change followed the order CON–MF > ORG–MF > CON–SFL > ORG–SFL. With BN, the order was ORG–MF > ORG–SFC > CON–SFC, and in DDF, both systems had very negative SOC change with the ORG–MF system showing a greater loss of SOC than the conventional reference. In the DOK experiment, SOC change was slightly positive in BIODYN and CON–MF, slightly negative in ORG–MF, and strongly negative in CON–MIN.

SOM balances calculated by HU-MOD do not closely match the estimated values for SOC change (Table 3), but the direction and relative extent of SOC change still is reflected in the variation in the SOM balance (Fig. 1). These relationships were significant, even though correlation coefficients often only were around $r=0.5$; the regression coefficients strongly differed from 1, and the

intercept was very variable as well, indicating that an absolute quantification of SOC change was not possible based on SOM balances calculated by HU-MOD.

Upscaling—cropland SOM balances for organic versus conventional farming in Germany

Cropping structure differs considerably between organic and conventional farming systems, with a higher proportion of perennial legumes in organic farming systems (Table 4). The pure cropland balance (scenario A) therefore shows a higher SOM balance for the organic cropland. Where catch crop area and straw fertilization are considered (scenario B), SOM balances increase in with both farming systems but remain higher in organic farming systems.

With scenario C (inclusion of animal manure availability), SOM balances for the two systems are at a comparable, slightly negative level. Conventional farming systems have a higher average livestock stocking rate of 1.28 LU ha^{-1} compared with 0.63 LU ha^{-1} with organic farming. In the scenario C calculations, it has been assumed that roughly 50 % of available animal manure is applied to arable land in conventional agriculture, as reported by Statistisches Bundesamt (2011). No specific numbers exist for organic farming, but, as extensive grassland management is very common with organic farming in many regions (Statistische Ämter 2011), we preliminarily assumed that 60 % of the available manure is applied on arable land in organic farming systems.

Discussion

Method performance in the long-term field experiments

The assessment of the SOC change from a series of measured SOM/SOC parameters is problematic because of the high spatial heterogeneity of SOM distribution (Hülsbergen et al. 2000; Papritz and Webster 1995). Moreover, the reliability of SOC and SON trends was limited for BL, BN, and DDF, as trends had to be calculated based on few, non-annual values (BN, DDF) or short time periods (BL). The significant correlation between SOC change modelled SOM balance at the farm-type aggregation level suggests that the simple model can be used in practice for the

Table 3 SOC change and SOM balances for organic versus conventional treatments in four long-term field experiments

Experiment	Farming system	SOC change (kg SOC ha ⁻¹ year ⁻¹)	SOM balance (kg SOCha ⁻¹ year ⁻¹)
BL	CON–MF	552 a	297 a
	CON–SFL	499 a	–206 c
	ORG–MF	500 a	58 b
	ORG–SFL	240 a	–275 d
BN	CON–SFC	216 a	–695 c
	ORG–SFC	118 a	–561 b
	ORG–MF	1581 b	–45 a
DDF	CON–MF	–514 a	–104 a
	ORG–MF	–1947 b	–123 a
DOK	CON–MF	109 a	327 c
	CON–MIN	–93 a	–426 d
	BIODYN	104 a	610 b
	ORG–MF	–30 a	725 a

Details of farming systems are described in Table 2. Different letters refer to significant differences at $\alpha=0.1$ between experimental treatments within each field experiment. The annual SOC change is the fitted gradient calculated of SOC change in the survey period. SOM balances were calculated using HU-MOD (Brock et al. 2012)

analysis of the likely trends in the impact of farming systems and/or farming structures on SOM level. The relevance of data quality also became evident in a separate validation of HU-MOD, where the model performed best in a field experiment with highly detailed data on SOM levels and SOM level development (Brock et al. 2012). This HU-MOD validation also showed a better performance of the model when considering treatment means rather than plot data, which is in line with the results in this paper.

The main advantage of the HU-MOD tool is that the model does not require any information on soil parameters, and texture or current SOM contents in particular. This allows the easy application of the model where such data are not available at the required scale to allow true quantitative modelling, as was the case in our survey. Of course, the advantage of this approach also leads to the limitation that quantification of absolute changes is not possible. This situation is recognized in the model scope (Brock et al. 2012) and is the reason why we did not apply common validation criteria that refer to a quantitative divergence between observed and predicted values, as root mean square error (*RMSE*), or modelling efficiency (*EF*) (see overview by Smith et al. 1997). However, the model allows for the assessment of the likely trends of impact on SOC change (better, indifferent, worse) in assessments of farming systems or management change where more sophisticated modelling is prevented by lack of (soil) data.

Our results show that organic farming does not in general show higher SOM balances and a more favorable

impact on SOC levels than conventional farming. The BL and DDF experiments comprise a comparison of integrated versus organic farming systems; under these conditions, conventional (integrated) farming had higher SOM balances and a more favorable impact on SOC levels than the organic farming systems with which they were compared. This observation is in line with results from long-term fertilization experiments, where additional mineral N fertilization usually produced higher yields (and returns of crop residues) which lead to SOM levels, if crop rotations and organic fertilization were held constant (Carlgren and Mattsson 2001; Shevtsova 2003). Leithold (1991) also concluded that mineral nitrogen fertilization of arable crops decreases the demand for nitrogen from SOM mineralization and thus contributes to a lower demand for organic matter supply to maintain SOM levels. Leithold's assumption is supported by the analytical results of Nissen and Wander (2003), and this mechanism has been implemented in the SOM balance model HU-MOD. A possible priming effect of mineral fertilization (Kuzyakov et al. 2000) must also be taken into account. However, the priming effect may be overcompensated by the lower N demand from SOM mineralization and the higher supply of crop residues as an effect of higher yield levels.

In the well-known DOK experiment, the two conventional systems M and K feature the same crop rotation as the organic systems D and O but differ in fertilization (Table 1). Crop rotation effects on SOM dynamics therefore do not occur, even though they may be more crucial than fertilization effects (Gregorich et al. 2001; Liu et al.

Table 4 SOM balance calculation for organic versus conventional cropland in Germany

Scenario and farming system	Crop area		Catch crop area		Straw fertilization		Livestock		Animal manure availability		SOM balance			
	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON	ORG	CON		
	1.000 ha		1.000 ha		1.000 ha		LU ha ⁻¹		t FM ha ⁻¹ a ⁻¹ m ³ ha ⁻¹ a ⁻¹		kg SOC ha ⁻¹ a ⁻¹			
Winter cereals	159.5	5664.9												
Summer cereals	43.0	533.0												
Corn	4.4	463.6												
Grain legumes	28.0	102.7												
Potatoes	8.2	255.2								2.0	(stable manure)			
Turnips	1.4	373.7	97	2841	43	5665	0.63	1.28	6.0 (stable manure)					
Canola	2.2	1473.4									+11.0	(slurry)		
Sunflower	2.0	25.4												
Flax	1.6	7.1												
Fodder legumes	132.5	720.5												
Fodder maize	6.5	1845.9												
Scenario A	considered		-----not considered-----								-342	-448		
Scenario B	considered				-----not considered-----						-317	-406		
Scenario C	considered												-92	-88

Database: BLE (2012) for cropland structure, BMELV (2007) for livestock calculation, Statistisches Bundesamt (2011) for catch crop area, and IFEU (2008) for straw removal. SOM balances calculated according to Brock et al. (2012)

2006). Within identical crop rotations, SOM inputs in crop residues will be higher within conventional farming systems, if yield levels are higher and nitrogen demand is supplied by fertilizers, and not by a higher absorption of SON (Brock et al. 2011). As a consequence, the different fertilization regimes in the DOK treatments did not lead to a clear differentiation between organic and conventional treatments (Leifeld et al. 2009). In this trial, significantly higher SOM levels were only observed comparing the D system (biodynamic management with compost-based fertilization) to the M system (conventional management with mineral fertilizer application only) (Fließbach et al. 2007; Mäder et al. 2002).

SOM balance for organic versus conventional cropland in Germany

For cropland in Germany, organic farming systems have a less negative SOM balance compared with conventional systems where no animal manure applications are considered. Where inputs of livestock manure are estimated, there is no difference between the SOM balances of the farming systems. However, these balances are a mean for the whole cropland area and therefore do not reflect the situation on single farms. From the BMELV (2007) report, it becomes obvious that livestock and thus animal manure application shows a strong regional concentration in Germany that

does not coincide with the main cash crop production areas. According to that source, livestock density on arable cash crop farms on average was only about 0.2 LU ha⁻¹ within both conventional and organic farming systems. On the other hand, livestock density was roughly 1.6 LU ha⁻¹ on average on conventional, but only 0.9 LU ha⁻¹ on organic animal production farms. Furthermore, Zerger and Haas (2003) reported that livestock on organic farms was between 0.06 LU and 1.26 LU ha⁻¹ in the German state of North Rhine-Westfalia when assessment was made at a communal level. Best (2007) found that at least 10 % of organic farms in a comprehensive survey had no livestock at all, while, on the other hand, roughly 30 % of farms had no cropland but only had grassland as they specialized in livestock production. With conventional farming, the specialization is even stronger: According to the 2010 official census, 43 % of farms in Germany were specialized in livestock; 25 % were specialized in arable cash crops, and only 15 % were mixed farms (Statistische Ämter 2011).

Specialization of farms and regional concentration of particular enterprises will have a considerable impact on the true SOM balances at farm and regional scales. However, the scenarios A and B without animal manure application point towards negative SOM balances in arable cash crop farming in both organic and conventional management systems. On the other

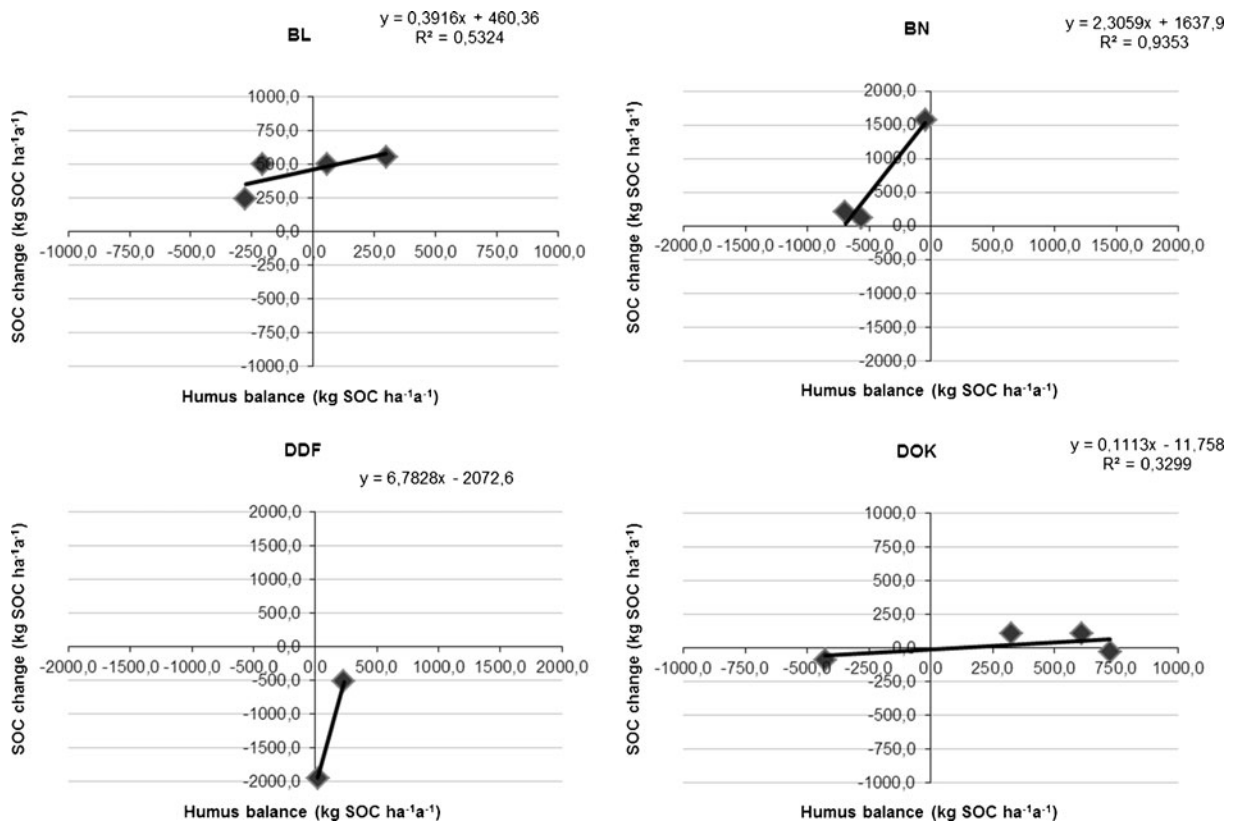


Fig. 1 Relation between SOM balances and SOC change in four long-term field experiments comparing organic and conventional farming systems. SOC change calculated as linear

trend of SOC change in the survey period, SOM balances calculated with the HU-MOD model (Brock et al. 2012)

hand, the concentration of livestock may lead to an excessive supply of nitrogen with regard to crop N demand balances in these regions, as indicated by the nitrogen balances (Osterburg and Schmitt 2008). An excessive supply of nitrogen thus decreases the N use efficiency and N utilization in the soil plant system. This situation is recognized in the HU-MOD model with the calculation of the N supply from SOM mineralization (Brock et al. 2012). While moderate N supply with fertilizers (i.e., N amounts that may be absorbed by the crops) leads to a decreased demand of N from SOM mineralization in the model, excessive supply will not lower the SOM loss parameter below a crop and yield specific threshold value. With regard to the calculated cropland scenarios, this situation means that a (considerable) amount of available N as indicated by average livestock size may actually not be applicable in the SOM balance due to specialization and concentration processes. Furthermore, the possibility of priming effects of N supply has been reported

(Kuzyakov et al. 2000) but has not yet been included in the model. Even though balances calculated with HU-MOD did not have a strong link to absolute SOC change in the field experiments, there is some evidence from surveys on SOC change in European croplands that the true SOM balance on arable land in fact may be negative on average (Bellamy et al. 2005; Kutsch et al. 2010; Schrupf et al. 2011).

It would be desirable to conduct a spatially more differentiated assessment supported by GIS, as, e.g., done by Sleutel et al. (2007) in a case study on agricultural management impact on SOM change in arable soils of Flanders (Belgium) at the community scale. These authors thus yielded spatially more explicit results. However, a database that would allow for a comparable spatially disaggregated assessment could not be compiled for our calculations and is not publicly available for Germany at present. Available GIS databases for European countries with a comparable high resolution, as LUCAS data (European Commission 2009), allow for

a spatial analysis of cropland with different crops and could, with repeated surveys, be utilized to calculate a cropland SOM balance (e.g., Britz et al. 2011; Leip et al. 2008), comparable to Scenario A in our study. However, LUCAS data do not provide differentiated information on actual crop rotations, fertilization, and farming systems and would therefore have to be supplemented by other databases for SOM balance calculation.

The high spatial aggregation substantially limits the power of our results but, still, the results both in general approve the applicability of a simple SOM balance approach for the intended assessment and provide valuable information on structural aspects of organic versus conventional farming that seem to be drivers of SOM dynamics. A regional, GIS-based modelling approach would, however, be highly desirable, and this would be particularly valuable, if explicit data on SOM change were included for validation of the results.

Conclusions

It was possible to explain the differentiation of SOM levels and SOM level development between treatments in long-term field experiments applying the SOM balance model HU-MOD. Higher SOM balances under comparable basic conditions (i.e., within a single field experiment) coincided higher SOM levels and a relatively more positive SOM level development. We therefore conclude that a shift from conventional to organic agriculture will have a positive impact on SOM levels, if the SOM balance level of the new management is higher than with the former management. Referring to the actual cropland structure in Germany, SOM balances of organic farming were more positive than with conventional farming in the scenarios without consideration of animal manure application, but balances for the two systems were not different in the scenario with consideration of animal manure application as an average for the whole cropland. However, the considerable specialization patterns in the agricultural production sector challenge the validity of this calculation, as especially animal manure availability and application shows a strong regional concentration that would affect the mean cropland balance if calculated based on disaggregated data.

Altogether, our results support the applicability of simple SOM balance models for the comparison of farming systems and cropland structures with regard to their impact on SOC levels but at the same time

imply a strong demand for studies with a sufficient spatial and structural resolution.

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References

- Bellamy P, Loveland P, Bradley R, Lark R, Kirk G (2005) Carbon losses from all soils across England and Wales 1978–2003. *Nature* 437:245–248
- Best H (2007) Organic agriculture and the conventionalization hypothesis: a case study from West Germany. *Agric Hum Values* 25:95–106
- BLE (2012) Strukturdaten Ökologischer Landbau 2010. http://www.oekolandbau.de/fileadmin/redaktion/dokumente/service/Bio-Strukturdaten_2010.xlsx Accessed 29 March 2012
- BMELV (2007) Agrarpolitischer Bericht der Bundesregierung 2007. German Federal Ministry of Agriculture and Food (BMELV) publication, Bonn
- Britz W, Verburg P, Leip A (2011) Modelling of land cover and agricultural change in Europe: combining the CLUE and CAPRI-Spat approaches. *Agr Ecosyst Environ* 142:40–50
- Brock C, Fließbach A, Oberholzer H, Schulz F, Wiesinger K, Reinicke F, Koch W, Pallutt B, Dittman B, Zimmer J, Hülsbergen K, Leithold G (2011) Relation between soil organic matter and yield levels of nonlegume crops in organic and conventional farming systems. *J Plant Nutr Soil Sci* 174:568–575
- Brock C, Hoyer U, Leithold G, Hülsbergen KJ (2012) The humus balance model (HU-MOD): a simple tool for the assessment of management change impact on soil organic matter levels in arable soils. *Nutr Cycl Agroecosyst* 92:239–254
- Carlgrén K, Mattsson L (2001) Swedish soil fertility experiments. *Acta Agr Scand B-S P* 51:49–78
- Debruck J (2003) Der viehlose Öko-Betrieb—die Problematik um Fruchtfolge und N-Kreislauf. *Mitt Ges Pflanzenbauwiss* 15:63–66
- Deike S, Pallutt B, Christen O (2008) Investigations on the energy efficiency of organic and integrated farming with specific emphasis on pesticide use intensity. *Eur J Agron* 28:461–470
- European Commission (2009): LUCAS 2009 (Land Use/Cover Area Frame Survey). Technical reference document C-1: general implementation, land cover and use, water management, soil, transect, photos. Surveyor instructions. http://epp.eurostat.ec.europa.eu/portal/page/portal/lucas/documents/Instructions_LUCAS2009m.pdf Accessed 6 June 2012
- Fließbach A, Oberholzer H, Gunst L, Mäder P (2007) Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. *Agr Ecosyst Environ* 118:273–284

- Foeroid B, Høgh-Jensen H (2004) Carbon sequestration potential of organic agriculture in northern Europe—a modelling approach. *Nutr Cycl Agroecosys* 68:13–24
- Foissner W (1992) Comparative studies on the soil life in ecofarmed and conventionally farmed fields and grasslands of Austria. *Agr Ecosyst Environ* 40:207–218
- Freibauer A, Rounsevell M, Smith P, Verhagen J (2004) Carbon sequestration in the agricultural soils of Europe. *Geoderma* 122:1–23
- Gosling P, Shepherd M (2005) Long-term changes in soil fertility in organic arable farming systems in England, with particular reference to phosphorus and potassium. *Agr Ecosyst Environ* 105:425–432
- Gregorich EG, Drury CF, Baldock JA (2001) Changes in soil carbon under long-term maize in monoculture and legume-based rotation. *Can J Soil Sci* 81:21–31
- Hepperly PR, Douds D, Seidel R (2006) The Rodale Institute Farming Systems Trial 1981 to 2005: long-term analysis of organic and conventional maize and soybean cropping systems. In: Raupp J, Pekrun C, Oltmanns M, Köpke U (eds) Long-term field experiments in organic farming, ISOFAR Scientific Series 1, Dr. Köster, Berlin, pp 15–32
- Hülsbergen KJ, Abraham J, Wittmann C, Papaja S (2000) Die räumliche und zeitliche Variabilität der Humus- und Nährstoffgehalte auf Testflächen in Seeben. In: Hülsbergen KJ, Diepenbrock W (eds) Die Entwicklung von Fauna, Flora und Boden nach Umstellung auf ökologischen Landbau, Martin-Luther-Universität Halle-Wittenberg, Halle, pp 69–86
- IFEU (2008) Nachhaltig nutzbares Getreidestroh in Deutschland. Positionspapier. Institut für Energie- und Umweltforschung Heidelberg GmbH (IFEU), Heidelberg. <http://www.ifeu.de/landwirtschaft/pdf/IFEU%20-%20Positionspapier%20Stroh.pdf>. Accessed 29 March 2012
- ISO 10694 (1995) Soil quality—determination of organic and total carbon after dry combustion (elementary analysis). International Standardization Organization
- Kirchmann H, Bergstroem L (2008) Organic crop production. Ambitions and limitations. Springer Science + Business Media B.V. [Dordrecht]
- Kutsch W, Aubinet M, Buchmann N et al (2010) The net biome production of full crop rotations in Europe. *Agric Ecosyst Environ* 139:336–345
- Kuzyakov Y, Friedel JK, Stahr K (2000) Review of mechanisms and quantification of priming effects. *Soil Biol Biochem* 32:1485–1498
- Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. *Science* 304:1623–1627
- Lal R (2006) Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands. *Land Degrad Dev* 17:197–209
- Leifeld J, Fuhrer J (2010) Organic farming and soil carbon sequestration: what do we really know about the benefits? *Ambio* 39:585–599
- Leifeld J, Reiser R, Oberholzer H (2009) Consequences of conventional versus organic farming on soil carbon: results from a 27-year field experiment. *Agron J* 101:1204
- Leip A, Marchi G, Koeble R, Kempen M, Britz W, Li C (2008) Linking an economic model for European agriculture with a mechanistic model to estimate nitrogen and carbon losses from arable soils in Europe. *Biogeosciences* 5:73–94
- Leithold G (1991) Über den Zusammenhang von Humus und Stickstoff im System Boden-Pflanze und Möglichkeiten einer quantitativen Beschreibung. *Wissenschaftliche Zeitschrift der Universität Halle XXXX'91M3:67-75*
- Liu X, Herbert SJ, Hashemi AM, Zhang X, Ding G (2006) Effects of agricultural management on soil organic matter and carbon transformation—a review. *Plant Soil Environ* 52:531–543
- Mäder P, Fließbach A, Dubois D, Gunst L, Fried P, Niggli U (2002) Soil fertility and biodiversity in organic farming. *Science* 296:1694–1697
- Mäder P, Fließbach A, Dubois D, Gunst L, Jossi W, Widmer F, Oberson A, Frossard E, Oehl F, Wiemken A, Gattinger A, Niggli U (2006) The DOK experiment (Switzerland). In: Raupp J, Pekrun C, Oltmanns M, Köpke U (eds) Long-term field experiments in organic farming, ISOFAR Scientific Series 1, Dr. Köster, Berlin, pp 41–58
- Marinari S, Mancinelli R, Campiglia E, Grego S (2006) Chemical and biological indicators of soil quality in organic and conventional farming systems in central Italy. *Ecol Indic* 6:701–711
- Mazzoncini M, Canali S, Giovannetti M, Castagnoli M, Tittarelli F, Antichi D, Nannelli R, Cristani C, Bärberi P (2010) Comparison of organic and conventional stockless arable systems: a multidisciplinary approach to soil quality evaluation. *Appl Soil Ecol* 44:124–132
- Munro TL, Cook HF, Lee HC (2002) Sustainability indicators used to compare properties of organic and conventionally managed topsoils. *Biol Agric Hortic* 20:201–214
- Nissen TM, Wander MM (2003) Management and soil-quality effects on fertilizer-use efficiency and leaching. *Soil Sci Soc Am J* 67:1524–1532
- Osterburg B, Schmitt T (2008) Weiterentwicklung der Berechnung regionaler Stickstoffbilanzen am Beispiel Niedersachsen. *Landbauforschung - vTI Agri For Res* 58:45–58
- Panten K, Rogasik J, Godlinski F, Funder U, Greef JM, Schnug E (2009) Gross soil surface nutrient balances: the OECD approach implemented under German conditions. *Landbauforschung-vTI Agr For Res* 59:19–28
- Papritz A, Webster R (1995) Estimating temporal change in soil monitoring. I. Statistical theory. *Eur J Soil Sci* 46:1–12
- Parton WJ, Schimel DS, Cole CV, Ojima DS (1987) Analysis of factors controlling soil organic matter levels in Great Plains Grasslands. *Soil Sci Soc Am J* 51:1173–1179
- Pierr A, Werner W (1998) Nachhaltige landwirtschaftliche Produktionssysteme im Vergleich. Bewertung anhand von Umweltindikatoren. DLG-Verl., Frankfurt a. Main [u.a.]
- Pulleman M, Jongmans A, Marinissen J, Bouma J (2003) Effects of organic versus conventional arable farming on soil structure and organic matter dynamics in a marine loam in The Netherlands. *Soil Use Manage* 19:157–165
- Reganold J (1988) Comparison of soil properties as influenced by organic and conventional farming systems. *Am J Alternative Agr* 3:144–155
- Reinicke F, Hülsbergen KJ, Christen O (2003) Bewertung von Anbausystemen des integrierten und ökologischen landbaus unter den Bedingungen des mitteldeutschen Trocken-

- Lößgebietes in einem Dauerfeldversuch. *Mitt Ges Pflanzenbauwiss* 15:42–45
- Schrumpf M, Schulze E, Kaiser K, Schumacher J (2011) How accurately can soil organic carbon stocks and stock changes be quantified by soil inventories? *Biogeosciences* 8:723–769
- Shepherd MA, Harrison R, Webb J (2002) Managing soil organic matter—implications for soil structure on organic farms. *Soil Use Manage* 18:284–292
- Shevtsova L (2003) Effect of natural and agricultural factors on long-term soil organic matter dynamics in arable soddy-podzolic soils—modeling and observation. *Geoderma* 116:165–189
- Sleutel S, De Neve S, Hofman G (2007) Assessing causes of recent organic carbon losses from cropland soils by means of regional-scaled input balances for the case of Flanders (Belgium). *Nutr cycl Agroecosyst* 78:265–278
- Smith P (2004) Carbon sequestration in croplands: the potential in Europe and the global context. *Eur J Agron* 20:229–236
- Smith P, Smith J, Powlson D, McGill W, Arah J, Chertov O, Coleman K, Franko U, Frohling S, Jenkinson D, Jensen L, Kelly R, Klein-Gunnewiek H, Komarov A, Li C, Molina J, Mueller T, Parton W, Thornley J, Whitmore A (1997) A comparison of the performance of nine soil organic matter models using datasets from seven long-term experiments. *Geoderma* 81:153–225
- Statistische Ämter (2011) Agrarstrukturen in Deutschland—Einheit in Vielfalt—Regionale Ergebnisse der Landwirtschaftszählung 2010. http://www.statistikportal.de/statistikportal/landwirtschaftszaehlung_2010.pdf. Accessed 29 March 2012
- Statistisches Bundesamt (2011) Wirtschaftsdünger tierischer Herkunft in landwirtschaftlichen Betrieben - Erhebung zur Wirtschaftsdüngerausbringung 2010. Fachserie 3 Reihe 2.2.2. https://www.destatis.de/DE/Publikationen/Thematisch/LandForstwirtschaft/ViehbestandTierischeErzeugung/Wirtschaftsduenger2030222109004.pdf?__blob=publicationFile. Accessed 29 March 2012
- van Diepeningen A, Devos O, Korthals G, van Bruggen A (2006) Effects of organic versus conventional management on chemical and biological parameters in agricultural soils. *Appl Soil Ecol* 31:120–135
- Zerger C, Haas G (2003) *Ökologischer Landbau und Agrarstruktur in Nordrhein-Westfalen*. 1st edn. Dr. Köster, Berlin