Response time of soil microbial biomass after conversion from conventional to several different organic farming systems

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Abstract

Organic farming was implemented on a 660 ha area of agricultural land with a long history of conventional farm management in Trenthorst, Northern Germany. The arable land was divided in five different organic farming systems differing in crop rotations and organic fertilization in addition to grassland plots. The plots were monitored over a period of seven consecutive years from 2001 to 2008 together with four adjacent plots which remained under conventional management. To assess the impact of soil management on the microflora, soil microbial quality indicators such as total microbial biomass (C_{mic}), the C_{mic}-to-C_{org} ratio together with soil carbon (C_{org}) were analyzed annually.

C_{mic} and C_{mic}-to-C_{org} ratio were sensitive parameters which differed in their responses dependent on the farming system and varied from no effects, to beneficial or adverse effects. Field plots under the system "DAIRY" with a high presence of legumes in the crop rotation in addition with FYM and slurry applications were the most favorable for microbial development with significant C_{mic} increases up to 87 % within seven years, with an annual growth rate of 12 to 53 µg C_{mic} g^{-1} soil and an increase of the C_{mic}-to-C_{org} ratio of up to 60 %. Plots under the system "PIG" showed losses in C_{mic} of up to 25 % and a decreased C_{mic}-to-C_{org} ratio of up to 27 %. The type of crop management here could be the reason for the insufficient microbial growth. A gradual loss of N_t and P was noted in most of the organic plots over the years. As a general observation it seems necessary to examine in closer detail the nutrient composition of plots under transition to organic farming for an optimal stimulation of microbial growth.

The conventionally managed plots had consistently high microbial indices, which correspond to those of plots under conversion to organic farming.

Keywords: *long-term soil monitoring; transition to organic farming systems; microbial biomass (C_{mic}); C_{mic}-to-C_{org} ratio; organic vs. conventional farming*

Zusammenfassung

Reaktionszeit der mikrobiellen Biomasse im Boden auf unterschiedliche ökologische Bewirtschaftungssysteme nach Umstellung von konventionellem Landbau

In Trenthorst, Norddeutschland, wurde auf einer Fläche von 660 ha mit langer konventioneller Nutzung Ackerland und Dauergrünland auf Ökologischen Landbau umgestellt. Fünf verschiedene Fruchtfolge- und Düngungssysteme wurden etabliert. Die 49 Flächen wurden zusammen mit vier Flächen, die unter konventioneller Bewirtschaftung blieben, von 2001 bis 2008 jährlich untersucht. Der Einfluss der Bodenbewirtschaftung auf die Mikroflora wurde anhand von Daten zur mikrobiellen Biomasse (C_{mic}), zum C_{mic}-zu-C_{org}-Verhältnis und zum Bodenkohlenstoff (C_{org}) ermittelt.

C_{mic} und das C_{mic}-zu-C_{org}-Verhältnis waren empfindliche Parameter, die abhängig vom Bewirtschaftungssystem unterschiedlich reagierten: von keiner, förderlicher oder bis zur negativen Wirkung. Flächen unter dem System „Milchvieh", mit hohem Anteil an Leguminosen in der Fruchtfolge und Stall- und Flüssigmist-Einbringung, waren mit Zunahmen von bis zu 87 %, mit einer jährlichen Zuwachsrate von 12 bis 53 µg C_{mic} g^{-1} Boden und einem Zuwachs des C_{mic}-zu-C_{org}-Verhältnisses bis zu 60 % am förderlichsten. Flächen unter dem System „Schweinehaltung" zeigten dagegen Verluste im C_{mic} und einen Rückgang der C_{mic}-zu-C_{org}-Verhältnisse. In den ökologisch bewirtschafteten Böden wurde ein gradueller Verlust an N_t und P festgestellt. Die unter konventioneller Bewirtschaftung verbliebenen Böden hatten beständig hohe mikrobielle Indizes, die denen der ökologisch bewirtschafteten Flächen entsprachen.

Schlüsselworte: *Boden-Dauerbeobachtung; Umstellung auf ökologischen Landbau; mikrobielle Biomasse (C_{mic}); C_{mic}-zu-C_{org}-Verhältnis; ökologische vs. konventionelle Landwirtschaft*

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1 Introduction

Along with the "Industrial Revolution" during the second half of the 18th century synthetic fertilizers and pesticides (the inorganic methods) were introduced in agriculture which seemed superior at that time for an efficient food production. These today so-called "conventional" farming practices replaced the traditional form of farming, the basis of the so-called "organic farming", to a great extent in the western world. However, during the last decades, world-wide concern has been growing that agricultural intensification leads to soil erosion, loss of organic matter and of biodiversity (Francaviglia, 2004) with an associated loss of soil fertility. The propagation of organic farming management and research again became an issue (review Diacono and Montemurro, 2010) as an alternative and with it the rise in "organic" food products in Europe and world-wide, concomitant with an increasing share of organic agricultural land in comparison to conventional practices (Yussefi et al., 2000; Willer et al., 2013).

Existing research-oriented long-term organic farming systems aroused the interest of a broader scientific community, since organic farming touches many areas – from soil development, productivity or environmental protection (e.g., Lindenthahl et al., 1996; FIBL, 2000; Emmerling et al., 2001; Stockdale et al., 2001; Agroscope FAL Reckenholz, 2004; Quintern et al., 2006; Birkhofer et al., 2008). Since the soil microflora was known to be the main driving agent for organic matter transformations (e.g., overview Lynch, 1991; review Emmerling, 2005), soil development, fertility and sustainability it seemed obvious to test the microflora as a possible soil quality indicator. Reviews on the interrelationship between the microbial compartment and biogeochemical cycling are given by Elliott (1997) and Pankhurst et al. (1997). A strong relationship between the amount of soil organic carbon and the soil microbial biomass carbon was detected (e.g., Adams and Laughlin, 1981; Jenkinson and Ladd, 1981; Brookes et al., 1984) and a direct linear relationship between these two parameters reported (Anderson and Domsch, 1980). It became evident that agricultural management practices influenced the C_{mic}-to-C_{org} ratio. It could be shown that percent C_{mic}-to-C_{org} was significantly higher in continuous crop rotation plots in comparison to monoculture plots (Anderson and Domsch, 1989). Any change in field management will obviously have effects on the soil microbial biomass. Particularly litter quality of the harvest residues is a key factor regulating microbial biomass activity (Dickinson and Pugh, 1974).That is, the status of soil microbial biomass provides an early indication of a change in comparison to soil chemical indices such as soil carbon (Powlson et al., 1987). Further studies supported evidence that the microbial biomass and further the C_{mic}-to-C_{org} ratio could be taken as soil quality indicators (e.g., Anderson and Domsch, 1986; Powlson et al., 1987; Witter et al., 1993; Anderson, 2003; Höper and Kleefisch, 2001; Joergensen and Emmerling, 2006).

The present study was carried out at the Thünen Institute of Organic Farming in Trenthorst/Wulmenau, Northern Germany. The concept encompassed research on organic cattle husbandry (dairy), organic sheep-, goat- and pig husbandry, organic grassland management and organic cash crop systems (stockless). Further information on the history, structure and management of these organic farming systems can also be found elsewhere (Rahmann, 2001; Schaub et al., 2007; www.thuenen.de/en/ol/, see project: Long-term effects of organic farming systems).

In the present investigation the microbiological parameters "microbial biomass and the C_{mic}-to-C_{org} ratio" were used as indices for estimating the impact and development of the microflora in the soils under the different organic farming management practices over a period of seven years aiming to understand better which soil treatment conditions provide the best environmental conditions for microbial growth and to examine the sensitivity of the C_{mic}-to-C_{org} parameter which denotes the availability of carbon to the microflora in a particular soil system. The study differs from similar investigations in its wide-ranging organic farming system approach and in that all farming systems are located in the same geographical area.

The present analysis should be seen as an interims report since from ecosystem analyses it is known that after a change it can take decades until a new final stable condition (climax) is reached (Odum, 1969).

2 Material and methods

2.1 Experimental site and soil properties

The research area of the Thünen Institute of Organic Farming at Trenthorst/Wulmenau encompasses 660 ha and is located in Northern Germany (farm midpoint 53°47′ N, 10°32′ E). The property has a long history of agricultural use going back to the Middle Ages. For that reason nearly all current experimental plots at the site have been used as permanent grassland or agricultural land for centuries, but at least for more than 40 years. Soil types on the site are classified as stagnic Luvisols (BGR, 2008) from boulder clay with silty-loamy texture. Bulk densities of the top soils are around 1.3 to 1.5 g cm^3. Average temperature and rainfall are 8.8 °C and 685 mm a^{-1}, respectively. Soils are characterized by sufficient plant available nutrients (N, P, K and Mg). Soil pH was on average 5.5 in grassland and 6.5 in arable land (Böhm et al., 2014; Ohm et al., 2015) and had remained quite stable over the years until the end of the monitoring period. Some initial soil properties are presented in Table 1.

2.2 Experimental design and soil sampling

The plots established for the organic farming trial comply with the EU directive No 834/2007 of June 2007 on organic production and labelling of organic products and repealing regulation (EEC) No 2092/91. During conversion to organic farming in 2001/02, the agricultural land of the research farm was divided into four permanent farming systems designated by the terms "DAIRY", "PIG", "STOCKLESS1" and "MIXED" and one free crop rotation "STOCKLESS2" together with permanent "GRASSLAND". These organic systems had different

Table 1
Initial soil conditions 2001 and one year after conversion 2003.

Plot No.	C_{org} [%]	pH $CaCl_2$	C_{mic} [µg g^{-1} soil]	C_{org} [%]	N_t [%]	P* CAL mg $100g^{-1}$	pH $CaCl_2$	Clay [%]	C_{mic} [µg g^{-1} soil]
	Year 2001			Year 2003					
1	1.10	6.4	292	1.25	0.12	10.0	6.7	16.0	298
2	1.15	6.5	288	1.85	0.18	8.9	5.0	10.5	326
3	1.10	6.4	270	1.07	0.13	9.3	6.6	14.1	276
4	1.23	6.4	258	1.13	0.11	9.7	6.7	15.6	296
5	1.21	6.7	409	2.07	0.21	12.4	6.7	16.9	719
6	1.30	6.9	380	3.67	0.41	20.9	6.2	15.4	765
7	1.23	6.8	350	2.06	0.20	11.7	6.8	18.1	622
8	1.20	6.6	350	1.34	0.13	9.8	6.9	17.8	359
9	1.20	6.6	353	1.30	0.12	8.1	6.8	19.0	367
10	1.14	6.3	346	1.21	0.12	6.4	6.6	17.2	281
11	1.18	6.4	328	1.12	0.09	6.2	6.8	12.8	332
12	1.22	6.6	451	1.48	0.14	8.6	6.9	17.6	337
13	1.23	6.2	360	1.27	0.09	7.7	6.9	16.2	234
14	1.09	6.5	397	1.36	0.13	n.d.	6.7	18.8	359
15	1.27	6.6	463	1.40	0.13	11.7	6.8	18.5	344
16	1.22	6.4	382	1.33	0.13	10.8	6.6	16.5	453
17	1.23	6.4	493	1.44	0.15	9.2	6.6	20.5	494
18	1.30	6.4	466	1.49	0.15	10.3	6.9	18.5	301
19	1.23	6.3	428	1.38	0.15	11.0	6.8	18.0	326
20	1.31	6.2	476	1.45	0.15	9.6	6.8	18.4	308
21	1.16	6.3	576	1.31	0.13	10.3	6.8	16.4	379
22	1.20	6.4	453	1.20	0.11	7.5	6.5	15.8	268
23	1.20	6.5	427	1.20	0.12	7.2	6.8	17.1	292
24	1.13	6.4	394	1.26	0.12	7.8	6.5	19.1	326
25	1.18	6.6	300	1.40	0.13	8.9	7.1	18.8	293
26	1.12	6.3	411	1.29	0.12	7.4	6.9	16.8	260
27	1.20	6.5	420	1.53	0.15	7.8	7.1	18.6	259
28	1.15	6.4	470	1.59	0.16	11.2	6.8	19.8	390
29	n.d.	n.d.	n.d.	3.31	0.34	16.0	5.4	15.1	667
30	n.d.	n.d.	n.d.	3.76	0.38	16.2	5.6	14.9	789
31	1.07	6.3	330	1.15	0.11	7.4	6.4	12.1	306
32	n.d.	n.d.	n.d.	4.98	0.52	12.7	7.8	15.9	1240
33	n.d.	n.d.	n.d.	4.47	0.46	19.0	5.7	18.1	1148
34	1.13	6.3	390	1.14	0.11	8.7	6.8	17.0	285
35	1.18	6.4	326	1.27	n.d.	8.0	6.4	20.3	n.d.
36	1.22	6.5	362	1.15	0.12	9.4	6.6	21.0	271
37	1.23	6.5	405	1.18	0.12	8.5	6.5	18.7	294
38	1.23	6.6	382	1.27	0.14	7.2	6.9	19.7	407
39	1.24	6.4	360	1.35	0.14	8.0	6.6	19.3	372
40	1.25	6.4	368	1.10	0.11	5.7	6.5	18.0	328
41	1.30	6.3	388	1.22	0.13	7.3	6.9	20.6	272
42	1.20	6.7	338	1.38	0.14	10.3	6.8	18.2	586
43	1.34	6.3	440	1.72	0.17	10.5	6.5	14.8	471
44	1.20	6.3	331	1.96	0.18	13.6	6.3	9.9	430
45	1.30	6.5	389	1.12	0.12	10.1	6.7	18.0	652
46	1.20	6.1	317	1.22	0.12	7.7	6.6	18.8	522
47	n.d	n.d.	n.d.	1.45	0.15	7.9	6.3	17.0	360
48	1.07	6.4	474	1.26	0.13	9.5	6.5	18.5	572
49	n.d.	n.d.	n.d.	1.61	0.18	9.8	5.8	17.4	728
50	n.d.	n.d.	n.d.	3.52	0.38	11.1	6.0	27.5	977
51	n.d.	n.d.	n.d.	1.67	0.16	3.8	6.8	20.5	504
52	n.d.	n.d.	n.d.	1.64	0.17	6.7	6.5	21.7	324
53	n.d.	n.d.	n.d.	1.62	0.17	10.5	6.8	21.9	435
pooled CV (%)	5.4	2.0	15.1	18.40	35.30	5.8	3.0	12.8	18
pooled mean	1.2	6.4	386	1.68	0.17	9.7	6.6	17.6	440

* Plant-available phosphate; n.d. = no data.

numbers of replicated plots (Figure 1). Under the "STOCKLESS2" rotation, the choice of crops was adapted to the market conditions of each year. Generally both stockless rotations received no livestock manure (Table 3) whereas on the other rotations livestock manure was applied regularly. Plots in pasture areas were grazed by cattle, sheep and goats. Clover grass fields under DAIRY were partially grazed by pigs in 2002 and 2003, and under PIG in 2006 (Table 2 and 3). Manure type and application as well as grazing of livestock in the year prior to soil sampling is indicated in Table 2.

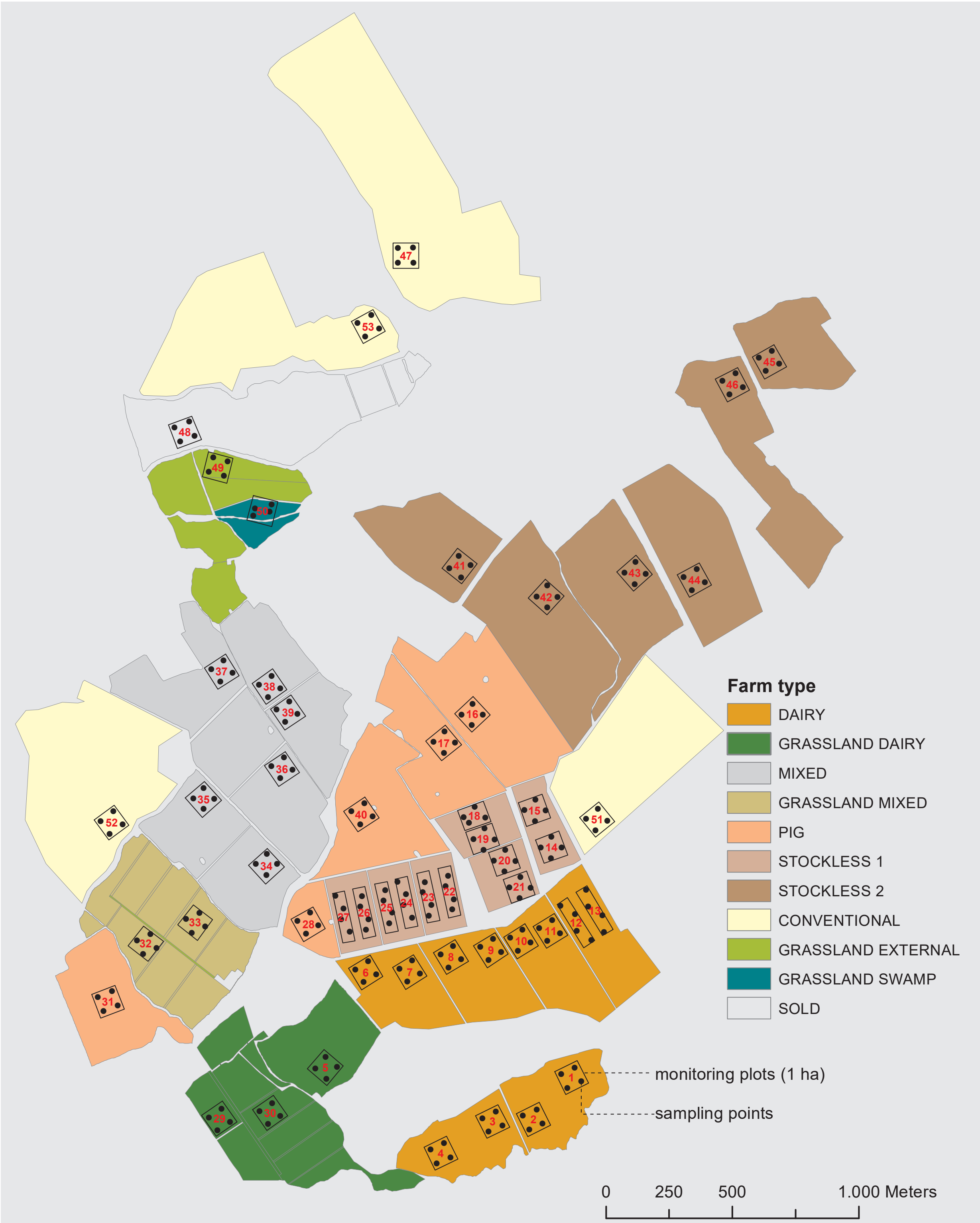

Figure 1
Structure of the long-term monitoring experiment at the Institute of Organic Farming, Trenthorst. Positions of different farming systems and position of fixed soil sampling points and monitoring plots.

Table 2
Crops in the long term monitoring plots and crop rotations of the different farming systems at the experimental farm Trenthorst, 2002 to 2008.

Plot	Farming system	Management	2001 (conversion)	2002 (conversion)	2003	2004	2005	2006	2007	2008
1-2	DAIRY[1]	organic	WRA	WT-OA	**CG1**	**CG2**	**WW**	**OA/FB^{SF}**	**FP/SB^{SF}**	**WT**
3-4	DAIRY	organic	WRA	WT	FB/OA^{L}	FP/SB	WT+CG^{F}	CG1^{SF}	CG2^{F}	WW^{F}
6-7	DAIRY	organic	WRA	CG1-CG1	CG2^{P}-CG2	WW^{PF}	OA/FB^{L}	FP/SB^{SF}	WT^{SF}	CG1^{SF}
8-9	DAIRY	organic	WB	WW	WT+CG^{U}	CG1^{U}	CG2^{U}	WW	OA/FB^{U}	FP/SB^{L}
10-11	DAIRY	organic	WB	CG1^{U}	WW	OA/FB^{F}	FP/SB	WT+CG^{S}	CG1	CG2^{S}
12-13	DAIRY	organic	WB	SM^{UF}	FP/SB	WT	CG1^{UF}	CG2	WW^{S}	OA/FB
5	DAIRY	organic	WRA	FP/CA^{F}	OA	GR^{C}	GR	GR^{S}	GR	GR^{S}
14-15	STOCKLESS1	organic	WB	CG1^{U}	SP+CG	CG1	WW	OA	FP	WRA^{L}
18-19	STOCKLESS1	organic	WW	CG1	FP	WRA	WT	CG	WW	OA/LI
20-21	STOCKLESS1	organic	CG1	WRA	WRA	SP	CW	WW	OA/LI	FP
22-23	STOCKLESS1	organic	WRA	CG1	OA	FP	WRA	WT	CG	WW^{L}
24-25	STOCKLESS1	organic	WRA	CG1	WW	OA	FP	WRA^{L}	WT	CG1
26-27	STOCKLESS1	organic	WRA	CG1	**CG2**	**WW^{L}**	**OA**	**FP**	**WRA**	**WT**
16	PIG	organic	WB	CG1	CG2	SW	BL	CG1	SM	FB^{S}
17	PIG	organic	WW	CG1	CG2	BL	CG1	SM	FB	WW
28	PIG	organic	WRA	CG1	CG2	CG3^{U}	CG4	CG5	SB^{P}	BL
31	PIG	organic	CG1	WRA	OA	FB^{US}	SB	CG1^{FL}	CG2	SM^{S}
40	PIG	organic	WRA	CG1	**CG2**	**CG3**	**SM**	**FB**	**BL^{F}**	**WT^{S}**
34	MIXED	organic	WW	LI	FP/CA	WW^{FL}	LI	WT	CG	WRA
35	MIXED	organic	WW	FP	SW	LI	WT^{F}	CG^{FL}	WRA	FP/CA
36	MIXED	organic	WW	FP/CA	SP+CG	CG	WRA	FP/CA^{UF}	WW^{UF}	LI^{UF}
37	MIXED	organic	WW	WW	LI	SP+CG^{F}	CG	WRA^{PF}	FP/CA	WW^{SF}
38	MIXED	organic	WW	BL	**CG1**	**WRA^{L}**	**FP/CA**	**WW^{F}**	**LI**	**WT**
39	MIXED	organic	WW	CG1	WRA	FP/CA	SW^{UF}	LI^{F}	WT	CG1
47	CONVENTIONAL	conventional	FB	WW	**WRA**	**WW**	WRA	WW	WRA	WW
52	CONVENTIONAL	conventional	WW	WW	**WRA**	**WW**	**WW**	WRA	WW	WW
53	CONVENTIONAL	conventional	WB	**WRA**	**WW**	**WB**	WRA	WW	SRA	WB
51	CONVENTIONAL	conventional	WBS	WRA^{S}	WW^{S}	WB^{S}	**WRA^{S}**	**WW^{S}**	**WB^{S}**	WRA^{S}
41	STOCKLESS2	organic	FP/SB	CG1	CW	CW^{UFL}	SW	FB+CP	CW	WW
42	STOCKLESS2	organic	WB	CG1	CG	SW	CW	WW	FB	CW
43	STOCKLESS2	organic	WW	SW	OA	CP	WW	FB/ SW+CG	CW	SP
44	STOCKLESS2	organic	WB	SP	OA	FB+CP	SRA+CW	CW	WW	OA/FB
45	STOCKLESS2	organic	CG1	CG2	CG3	SW	CP/OA	SP	FB	SW
46	STOCKLESS2	organic	CG1	CG2	CG3	SW	FB/SB	CW	FP	FP/SB
29	GRASSLAND DAIRY	organic	GR	GR	GR^{C}	GR^{C}	GR^{C}	GR^{CS}	GR	GR^{C}
30	GRASSLAND DAIRY	organic	GR	GR	GR^{C}	GR^{C}	GR^{C}	GR	GR^{S}	GR^{CS}
49	GRASSLAND EXTERNAL	organic	GR	GR	GR^{R}	GR^{R}	GR^{R}	GR^{R}	GR^{C}	GR^{C}
32	GRASSLAND MIXED	organic	GR	GR	GR^{R}	GR^{R}	GR^{R}	GR^{RS}	GR^{R}	GR^{R}
33	GRASSLAND MIXED	organic	GR	GR	GR^{R}	GR^{R}	GR^{R}	GR^{R}	GR^{R}	GR^{R}
50	GRASSLAND SWAMP	organic	GR	GR	GR^{R}	GR^{R}	GR^{R}	GR^{CR}	GR^{C}	GR^{C}
48	SOLD 2005	organic	CG1	CG2	CG3	CG4	-	-	-	-

[1]Fixed crop rotation schemes in the farming systems during the harvest years 2003 to 2008 are underlined; ^{F} = farm yard manure (solid) or ^{S} = slurry (liquid) or ^{U} = urine and seepage from stables, application in the year before soil sampling; ^{L} = lime application in the year before soil sampling, ^{C} = cattle, ^{P} = pigs, ^{R} = small ruminants (goats and/or sheep) grazing in the year before soil sampling; / = indicates mixed cropping; + = indicates undersown clover varieties

Crops in harvest year: BL = *Lupinus angustifolius* – blue lupin, CA = *Camelina sativa* – false flax, CG = *Trifolium pratense* or *T. repens* – red or white clover grass, CG1 = clover grass first year, CG2 = clover grass second year, CGn = clover grass year n, CP = *Trifolium resupinatum* – persian clover, CW = *T. repens* – white clover, FB = *Vicia faba* – field beans, FP = *Pisum sativum* – field peas, GR = permanent grassland, LI = *Linum usitatissimum* – linseed, OA = *Avena sativa* – oats, SB = *Hordeum vulgare* – spring barley, SM = *Zea mays* – silage maize, SP = *Triticum spelta* – spelt wheat, SRA = *Brassica napus* – spring rape, SW = *Triticum aestivum* – spring wheat, WB = *Hordeum vulgare* – winter barley, WRA = *Brassica napus* – winter rape, WT = *xTriticosecale* – winter triticale, WW = *Triticum aestivum* – winter wheat.

Additionally four plots with permanent CONVENTIONAL management (two-to-three field rotations, cereal-rapeseed or cereal-cereal-rapeseed, respectively) were surveyed (Figure 1, Table 2).

Altogether 53 long-term monitoring plots were implemented in the fields of the different farming systems (31 in organic ploughland, 4 in conventional ploughland and 6 in organic grassland) (Figure 1, Table 2). Fields differed in size (3 to 25 ha). Conventional fields and the majority of organic fields consisted of one monitoring plot of 1 ha each with the exception of "DAIRY" and "STOCKLESS1" farming systems, where two monitoring plots were established in each field for further in-field comparisons. Per plot four sampling points at a distance of 60 m from each other were generally arranged in squares. In narrow fields the monitoring sites were stretched (rectangular) to cover one hectare and the points are located in (zig-zag) with distances of 30 m from each other (Figure 1). Their geographical positions were determined and re-addressed each year for sampling by a real-time DGPS system with sub-meter accuracy (Trimble Pro XR/GPS Beacon). In practice this means a deviation of up to 0.3 m from a fixed point. In total 212 soil samples were taken each year between February and March. Samples were taken as mixed samples with a gouge auger in an area of five meter diameter around the permanent sampling points. Sampling depths were 30 cm in arable land (plough layer) and 10 cm in permanent grassland.

The long-term plot No. 48 "GRASSLAND" was sold and therefore only analyzed until 2005. This field came from arable farming in 2001 and was left under clover grass from this year onwards. The long-term plot No 5 (DAIRY) changed from arable cropland to permanent grassland in 2004 (Table 2).

Prior to conversion the initial values for soil microbial carbon (C_{mic}), soil organic carbon (C_{org}) and pH were determined in spring 2001 for all plots with the exception of CONVENTIONAL and GRASSLAND plots where measurements started the year 2003. The first soil analyses after conversion began with the year 2003; in addition to $C_{mic,}$ C_{org} and pH determinations also N_t, P and clay content were determined (Table 1) and the development of these variable parameters was followed each year until 2008. Crop roations were changed to the demands of organic farming after harvest in 2001. Clover grass and grain legumes as biological N sources were introduced (Table 2).

2.3 Soil handling and analysis

After air drying and sieving of the top soil at 2 mm, total C and total N in soils were determined after dry combustion in a HEKAtech elemental analyser EuroEA 3000.

The absence of carbonates in the top soils at the experimental site is generally known. This was frequently re-checked by testing the effervescence of the soil samples after addition of 1M HCl. So total C contents from elemental analy-sis were taken as C_{org} contents of the soils.

The plant available P fraction was determined as P (CAL) by photometrical determination after Schüller (1969).

The clay content was determined by the Köhn pipette technique (Köhn, 1928).

Soil pH was determined in the sieved probe by measurement in 25 ml 0.01 mol/l $CaCl_2$ with a pH electrode after two hours.

For C_{mic} analyses soils were stored in cool boxes in the field immediately after sampling and frozen at -20 °C on the same day. C_{mic} contents were analysed in the same year.

2.4 Microbial biomass determinations

Frozen samples were left to thaw at +4 °C and left at room temperature for ~ 4 days before measurements were made.

Table 3

Overview of the main treatments to the soil sites under different farming systems after conversion to organic farming and the conventional sides.

Farming system	soil cultivation (times per annum)	type of fertilizer*	main crop category	with crop residues	way of weed control	disease control	with livestock
GRASSLAND	-	slurry (some sites)	permanent	1-2 cuts, grazing	mowing	-	yes
DAIRY	Stubble cultivation 2x ploughing 1x seedbed preparation 2x	**FYM, slurry**, seepage	2/3 with legumes	1/3	mechanical	-	yes, grazing pigs on plots 6/7 in 2002 resp. 2003
STOCKLESS1		a)	1/3 with legumes	1/1	mechanical	-	-
STOCKLESS2		b)	1/3 -2/3 with legumes	2/3	mechanical	-	-
PIG		**slurry, seepage**, FYM	1/3-2/3 with legumes	2/3	mechanical	-	yes, grazing pigs on plot 28 in 2006
MIXED		**FYM**, slurry, seepage	1/2 with cereals/ linseed	1/2	mechanical	-	-
CONVENTIONAL		**one site slurry + mineral; rest mineral**	1/2 to 2/3 cereals	1/1	herbicides	pesticides	-

*Manure type in descending order of the number of applications of each type in the different farming system; types: FYM = farm yard manure (solid); slurry = faeces and urine (liquid); seepage = urine and other seepages from stables; [a)] Plots 14-15 received seepage in 2002; [b)] Plot 41 received FYM+slurry in 2004.

Soils were sieved (2 mm) and adjusted to a water holding capacity (WHC) of ~50 % (~240 kPa) prior to soil microbial analyses.

Microbial biomass was determined using the Anderson and Domsch (1978) substrate-induced respiration technique (SIR) . Samples of 25 g (dry weight) of soil were amended with 2000 µg g^{-1} glucose in 500 mg talcum. The CO_2 production rate was measured at 22°C using an automated infrared-gas analyzer system (Heinemeyer et al. 1989). The C_{mic}-to-C_{org} ratio is given as the percentage of C_{mic} in total C_{org}.

Mean values of C_{mic} and C_{mic}-to-C_{org} ratio of the 53 plots are based on four replicated samples per plot with three measurements per sample.

2.5 Procedure to collect and aggregate the data for long-term monitoring

A statistical analysis (one-way ANOVA) of the initial C_{mic} data (2001 or 2003) of replicated plots of the implemented organic farming systems revealed that the level of the microbial biomass was in part significantly different. That is, the initial starting situation of replicated plots was not homogeneous and could be related to a lower or higher C_{org} content. Therefore those C_{mic} data of replicated plots were pooled which were not statistical different. As listed in Table 4, this was done for DAIRY-, PIG-, GRASSLAND- and CONVENTIONAL farming systems.

The analyses of the development of C_{mic} in the farming systems "STOCKLESS1" and "MIXED" did not start until 2003. This step proved to be necessary, as these two soil systems

Table 4

Impact of farming systems on microbial biomass indices and C_{org}. Comparison was made between the initial arithmetic mean values previous to the change of the farming system and the final values. The probability value (*P*) depicts the strengths of change.

Farming system	Plot No.	(n)	Year	C_{mic} (µg g^{-1}soil)	*P*-value	Year	C_{mic}-to-C_{org} (%)	*P*-value	Year	C_{org} (%)	*P*-value
DAIRY	1- 4	(16)	2001 2008	278 ± 15.7 363 ± 31.6	*< 0.001*	2001 2008	2.4 ± 0.18 2.8 ± 0.20	*< 0.001*	2001 2008	1.14 ± 0.10 1.28 ± 0.05	*< 0.001*
DAIRY	6-13	(32)	2001 2008	353 ± 14.8 432 ± 43.4	*< 0.001*	2001 2008	2.6 ± 0.40 2.9 ± 0.60	*0.022*	2001 2008	1.21 ± 0.08 1.50 ± 0.50	*0.001*
DAIRY	5	(4)	2001 2008	409 ± 81.7 764 ± 11.4	*0.002*	2001 2008	3.4 ± 0.70 5.5 ± 0.90	*0.010*	2001 2008	1.20 ± 0.08 1.40 ± 0.05	*0.007*
STOCKLESS1	14, 15, 18-27	(48)	2003^{+} 2008	310 ± 40.2 394 ± 47.3	*< 0.001*	2003 2008	2.2 ± 0.30 3.0 ± 0.40	*< 0.001*	2003 2008	1.35 ± 0.11 1.30 ± 0.12	*0.036*
PIG	16, 31, 40	(12)	2001 2008	360 ± 26.9 298 ± 16.9	*0.007*	2001 2008	3.1 ± 0.30 2.7 ± 0.30	*0.004*	2001 2008	1.18 ± 0.10 1.16 ± 0.10	*0.629*
PIG	17, 28	(8)	2001 2008	482 ± 16.3 360 ± 61.2	*< 0.001*	2001 2008	4.0 ± 0.20 2.9 ± 0.26	*< 0.001*	2001 2008	1.20 ± 0.06 1.40 ± 0.23	*0.032*
MIXED	34-39	(24)	2003^{+} 2007	326 ± 60.0 347 ± 38.2	*0.159*	2003 2007	2.7 ± 0.30 2.9 ± 0.30	*0.040*	2003 2007	1.20 ± 0.08 1.20 ± 0.07	*1.000*
CONVENTIONAL	47, 52	(8)	2003^{+} 2008	342 ± 25.0 381 ± 64.9	*0.135*	2003 2008	2.2 ± 0.30 2.6 ± 0.40	*0.040*	2003 2008	1.54 ± 0.13 1.70 ± 0.51	*0.404*
CONVENTIONAL	51, 53	(8)	2003^{+} 2008	450 ± 20.6 425 ± 5.80	*0.006*	2003 2008	2.7 ± 0.14 2.6 ± 0.05	*0.078*	2003 2008	1.64 ± 0.04 1.61 ± 0.02	*0.079*
STOCKLESS2	41-46	(24)	2001 2008	367 ± 46.8 344 ± 66.2	*0.164*	2001 2008	2.9 ± 0.49 2.8 ± 0.48	*0.479*	2001 2008	1.26 ± 0.06 1.21 ± 0.20	*0.247*
GRASSLAND DAIRY	29, 30	(8)	2003 2008	728 ± 86.3 895 ± 8.0	*< 0.001*	2003 2008	2.8 ± 0.12 3.1 ± 0.30	*0.02*	2003 2008	3.50 ± 0.3 2.90 ± 0.30	*0.001*
GRASSLAND EXTERNAL	49	(4)	2003 2008	728 ± 217.3 702 ± 114.3	*0.839*	2003 2008	4.5 ± 1.3 3.7 ± 0.55	*0.30*	2003 2008	1.60 ± 0.3 1.89 ± 0.09	*0.114*
GRASSLAND MIXED	32, 33	(8)	2003 2008	1194 ± 65.0 1158 ± 68.9	*0.314*	2003 2008	2.5 ± 0.16 3.0 ± 0.10	*0.001*	2001 2008	4.70 ± 0.2 3.85 ± 0.04	*< 0.001*
GRASSLAND SWAMP	50	(4)	2003 2008	977 ± 142.5 1435 ± 58.8	*0.001*	2003 2008	3.0 ± 0.19 2.9 ± 0.30	*0.59*	2001 2008	5.10 ± 0.3 4.90 ± 0.50	*0.518*
GRASSLAND SOLD	48	(4)	2001 2005*	474 ± 44.5 552 ± 68.2	*0.104*	2001 2004	4.4 ± 0.49 5.5 ± 1.00	*0.099*	2001 2004	1.07 ± 0.06 1.00 ± 0.15	*0.423*

$^{+}$Sites with deviating start and end measurements (see Material and methods, Section 2.5). (n) Number of sampling points. ± Standard deviation of the mean. *P*-value was calculated using Student`s t-test. C_{mic} = soil microbial biomass; C_{org} = organic carbon content. *Plot was sold 2005 (see Material and methods, Section 2.2).

showed an extreme loss in C_{mic} of 30 % (STOCKLESS1) and 17 % (MIXED), respectively, after conversion. The initial values for 2001 were 438 µg C_{mic} g^{-1} soil for "STOCKLESS1" and 390 µg g^{-1} for "MIXED" plots, respectively. Also, the analyses for plots under "MIXED" management were discontinued the year 2007, since C_{mic} values had again declined (Table 4).

2.6 Re-measurements of C_{org} and N_t of some plots the years 2012 to 2014

Since the end of the monitoring period in the year 2008, the development of C_{org} and N_t was determined further yearly in all fields under "DAIRY", STOCKLESS1", "GRASSLAND" and "MIXED"; the remaining farming systems were resampled every fifth year (see Result section 3.4).

2.7 Statistics

A SigmaPlot 11.0 statistic package (Copyright© Sysstat Software Inc., 2008, Chicago, U.S.A) was used for one-way ANOVA analyses (Holm-Sidak method, significance level at least = 0.05) and Student's t-test.

3 Results

3.1 Microbial biomass development

The most favorable conditions for microbial development after conversion from conventional to organic farming were found in field plots under "DAIRY" farming. With respect to the initial microbial biomass values in the year 2001, increases from 22 % up to 87 % (plot No. 1 to 4, 6 to 13 and 5, respectively) were registered 2008 at the end of the monitoring period. These increases were highly statistically significant in the range from $p < 0.001$ to 0.002 (Table 4). This was followed by some field plots under "GRASSLAND": GRASSLAND DAIRY (plot No. 29, 30) had significant increases of 23 %, GRASSLAND SWAMP (plot No. 50) 47 %, followed by GRASSLAND SOLD (plot No. 48) with 17 % (here within four years only). Further, plots under "STOCKLESS1" (plot No. 14, 15, 18 to 27) showed a mean increase of 27 % within six years starting here from the year 2003 onwards (Table 4). The positive trend in microbial biomass development is exemplarily presented in Figure 2a,b showing plots under "DAIRY" management. No change of the microbial biomass status was registered in plots under either "MIXED" or "STOCKLESS2" while the farming system "PIG" showed indications of microbial biomass losses of 17 % (plot No. 16, 31, 40) and 25 % (plot No. 17, 28) which were highly statistically significant (Table 4).

Plots left under CONVENTIONAL management remained relatively stable with respect to the level of microbial biomasses during the monitoring period (Figure 3).

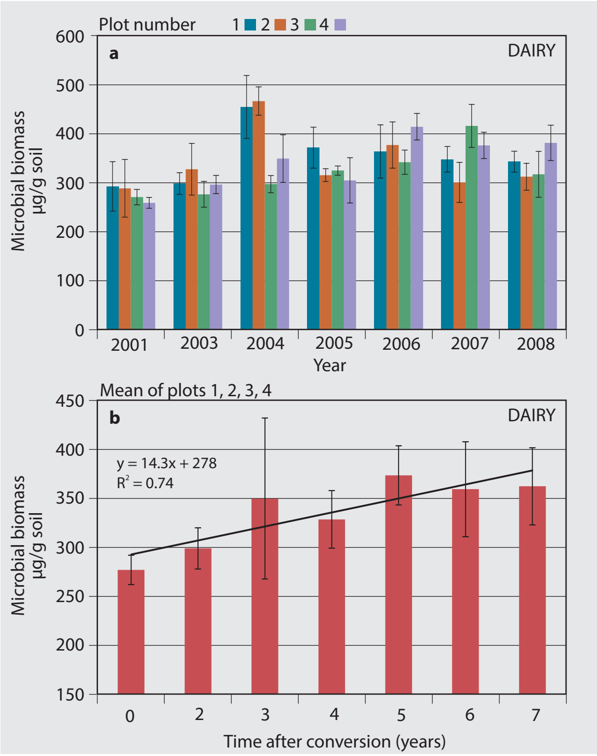

Figure 2a, b
(a) Example of microbial biomass-C content over time of plot No. 1, 2, 3, 4 under "DAIRY" management (n = 4) and **(b)** the annual mean values of those plots and generated regression analysis after conversion to organic farming (n = 16). Error bars show standard deviation of the mean.

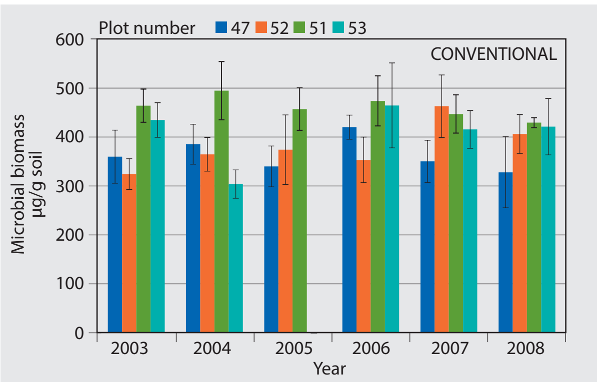

Figure 3
Microbial biomass-C content over time of four plots left under "CONVENTIONAL" management. Error bars show standard deviation of the mean; (n = 4).

3.2 C_{mic}-to-C_{org} development

In order to determine which farming system exerts the most positive effect in terms of microbial biomass development, the C_{mic}-to-C_{org} development was monitored, since this quotient reflects the carbon and nutrients in soil available for growth by the soil microflora. Along with the increase of the soil microbial biomass there are also significant increases in the C_{mic}-to-C_{org} ratios in plots of "DAIRY" and "STOCKLESS1" farming systems. Also here the DAIRY plot number 5 showed the highest increase of >60 % (Table 4, Figure 4). Also significant increases were seen for two "GRASSLAND" systems, GRASSLAND DAIRY and GRASSLAND MIXED, respectively. The systems "MIXED" and "STOCKLESS2" showed neither a positive nor negative trend, while the system "PIG" pointed to a negative trend which was significant. In the "CONVENTIONAL" managed systems this quotient remained relative stable. The apparent increases here for plots No. 47 and 52 are due to the fact that the initial value of the year 2003 started with 2.2 % C_{mic}-to-C_{org}, however in the following years this quotient remained around 2.6 (Table 4).

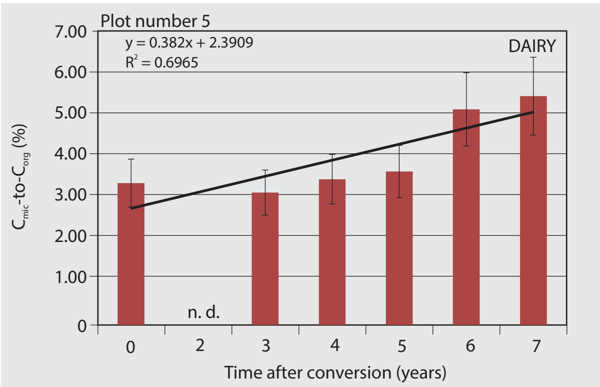

Figure 4

Example of the C_{mic}-to-C_{org} development over time and generated regression analysis depicting plot No. 5 under "DAIRY" management after conversion to organic farming being replaced by permanent "GRASSLAND" after three years. Error bars show standard deviation of the mean; (n = 4).

3.3 Growth rate determination by linear regression analysis of microbial indices

In order to verify whether the farming systems with beneficial qualities for microbial biomass development (as seen in Table 4) are real and in how far already increases could be regarded as a sustainable trend, the results were submitted to linear regression analyses on a yearly basis (Figure 2b and Figure 4**)**. Table 5 shows the coefficient of variation (r^2) together with the *p*-value. Considering these units it can be stated that only in plots under "DAIRY" farming system and "STOCKLESS1" farming system the microbial indices (C_{mic} and C_{mic}-to-C_{org}) are lastingly promoted already within seven years after conversion from conventional to organic farming management with an annual growth rate between 12 µg C_{mic} to 50 µg C_{mic} g^{-1} soil, respectively, here again plot 5 under "DAIRY" showed the highest annual increase rate. The C_{mic} increases as seen in some plots under "GRASSLAND" (GRASSLAND DAIRY, GRASSLAND SWAMP) should be considered as a positive trend only; the insufficient r^2 and *p*-values were due to the greater fluctuations over the monitoring period (Table 5).

Table 5

Linear regression analysis of soil microbial parameters of plots with significant increases or trends of increases during the years after start of the experiment until 2008.

Farming system	Plot No.	Dependent parameter	Equation	R^2	P-value
DAIRY	1-4	C_{mic}	y = 14.3x + 278.6	0.74	*0.008*
		C_{mic}-to-C_{org}	y = 0.14 + 2.2	0.60	*0.05*
DAIRY	6-13	C_{mic}	y = 12.5x + 331.5	0.74	*0.02*
		C_{mic}-to-C_{org}	y = 0.11x + 2.31	0.60	*0.07*
DAIRY	5	C_{mic}	y = 52.73x + 288.7	0.72	*0.05*
		C_{mic}-to-C_{org}	y = 0.38x + 2.40	0.70	*0.02*
STOCKLESS1⁺	14, 15, 18-27	C_{mic}	y = 15.4x + 297	0.69	*0.04*
		C_{mic}-to-C_{org}	y = 0.17x + 2.0	0.82	*0.013*
GRASSLAND⁺ DAIRY	29, 30	C_{mic}	y = 10.9x + 982	0.01	*0.56*
		C_{mic}-to-C_{org}	y = 0.047x + 3.37	0.010	*0.85*
GRASSLAND⁺ SWAMP	50	C_{mic}	y = 103.9x + 1042	0.27	*0.76*
		C_{mic}-to-C_{org}	y = 0.19x + 2.80	0.105	*0.53*

⁺Sites with deviating start measurements (see Material and methods, Section 2.5).

3.4 Observations on C_{org} and other soil parameters

With respect to the C_{org} development significant increases in all "DAIRY" plots and "PIG" managed systems (plot No.17, 28) were found. In the other plots no changes or reductions were registered (Table 4). After termination of the experiment in the year 2008, C_{org} together with N_t development has been pursued further in some selected field plots (Paulsen, 2015, personal communication). Some final measurements of the year 2014 on C_{org} are given in Table 6. Comparing these results with the data of 2008 (Table 4) some plots under GRASSLAND and MIXED showed increases in C_{org}, while C_{org} values of the other farming systems stayed relatively stable with the exception of some plots under "DAIRY" (plots 6 to 13, Table 4). The differences in the microbial mode of growth activity cannot be explained by the underlying soil conditions so far, since the ploughland plots of the different organic systems had similar levels of C_{org}, N_t, pH (2001), P or clay (2003) (Table 1) with the exception of DAIRY plot No 5 with the highest growth rate and the highest level in C_{org}, N_t and P.

Since P is considered to be a growth promotor for microbial cells, re-analysis were made 2008. All ploughland and some GRASSLAND plots showed lower values in plant available soil P (CAL), with decreases over 30 % for the system STOCKLESS2 when compared to 2003 (data not shown), yet, with no corresponding decrease of C_{mic} or C_{mic}-to-C_{org} indices.

Also a general trend of a slow decline in N_t over an observation period of 14 years (Paulsen, 2015, personal communication) was noted; this trend already became apparent in 2008, which is reflected in a slight increased C:N ratio in the majority of fields (Table 7).

For comparative purposes additional information and analyses on i.a. microbial indices can be extracted from the compilation of organic farming systems which were implemented world-wide (Table 8).

Table 6

C_{org} in soils after continuous cropping in long term plots of the systems DAIRY, STOCKLESS1, CONVENTIONAL, GRASSLAND in 2014 (Paulsen, 2015, personal communication).

Farming system	Plot No.	(n)	C_{org} (%)
DAIRY	1, 3	8	1.22 ± 0.15
	7, 9, 10, 12	16	1.24 ± 0.16
STOCKLESS1	15, 18, 20, 23, 25, 27	24	1.30 ± 0.20
PIG	17	4	1.41 ± 0.10[a]
MIXED	37-39	12	1.30 ± 0.20[b]
CONVENTIONAL	51, 53	8	1.69 ± 0.21
GRASSLAND DAIRY	29, 30	8	3.58 ± 0.43
GRASSLAND EXTERNAL	49	4	2.21 ± 0.17
GRASSLAND MIXED	32, 33	8	4.29 ± 1.71

[a]year 2013, [b]year 2012.

Table 7

The carbon-to-nitrogen ratio (C:N) in the year 2003 and 2008 in the different managed soil systems.

Farming system	Plot No.	C:N Year 2003	C:N Year 2008
DAIRY	1- 4	9.7	10.5
DAIRY	6-13	10.7	10.8
DAIRY	5	9.9	10.4
STOCKLESS1	14, 15, 18-27	10.3	11.3
PIG	16, 31, 40	10.0	10.0
PIG	17, 28	10.1	10.0
MIXED	34-39	9.7	9.4
CONVENTIONAL	47, 52	9.6	10.1
CONVENTIONAL	51, 53	9.7	9.9
STOCKLESS2	41-46	10.0	10.0
GRASSLAND DAIRY	29, 30	9.8	10.2
GRASSLAND EXTERNAL	49	9.2	10.3
GRASSLAND MIXED	32, 33	9.8	10.4
GRASSLAND SWAMP	50	9.3	10.0
GRASSLAND SOLD (2005)	48	9.7	9.4

4 Discussion

In view of the results available from this long-term study, it must be noted that conversion from conventional to organic farming systems will not in all cases immediately initiate beneficial effects with respect to microbial growth development. The development of the microbial biomass indices in the six different organic farming systems after conversion from conventional management (changing crop rotations, grassland use and fertilizer inputs) varied considerably after seven years – ranging from beneficial to detrimental effects. The results of this study are in accordance with data from a number of single case studies from literature research as provided in Table 8. Although here many of the study sites recorded positive effects after farming conversion at even shorter time intervals as in our study, sometimes no beneficial effects were recorded, or only after a matter of decades, as is exemplified by the sequence of publications of the study site DOK, Reckenholz, Switzerland. According to Odum (1969), after a change, ecosystems in general again tend to develop towards a stable final condition (climax) with a balance in energy and bio-element economy, if the new conditions remain constant over long periods of time. It can be assumed that the soil of the agricultural area where the different organic farming systems were implemented was in a quasi-steady state after decades of classical conventional farming management. This may be evidenced by those plots which were left under conventional management where biomass and C_{org} values remained quite even during the monitoring period with only minor fluctuations and with no detectable positive or negative trends (Figure 3, Table 4). The work of Smith (2004) displays how long it may take until a change in C_{org} can be detected – the higher the annual carbon input to the soil the higher the increase in C_{org} within a shorter time period. In our study, the soils which were converted from conventional to different organic farming systems are still in a transitional phase to a new equilibrium. This is since re-measurements of C_{org} and N_t the years 2012 to 2014 showed still no constancy of these parameters for most of the farming systems as can be seen by slight increases of the respective C:N ratios (Table 7).

The degree of impact of the type of field management of the implemented organic farming systems on the microflora is different whereby plots under DAIRY showed the fastest microbial growth rate in comparison to all the other implemented organic systems whereas microbial indices under the system PIG declined. This direct influence which field management can exert on the microflora is exemplified with DAIRY plot No. 5, which had changed from the initial ploughland to permanent grassland in the year 2004 with additional grazing and manure application; this plot showed the highest increase in C_{mic} and C_{mic}-to-C_{org} (Table 4, Figure 4). Soil plots of two farming systems (STOCKLESS1 and MIXED) showed microbial biomass decreases of 12 % and 30 %, respectively, after the first year of conversion (Material and methods section 2.5). Whereas microbial indices in plots under "STOCKLESS1" recovered the following year with continuing increases annually, microbial indices under "MIXED"

Table 8
Reported responses of microbial indices after conversion from conventional to organic farming listed by publication date.

Experimental system/Site	Years under observation	Microbial parameter	Response	References
Kutztown, Pennsylvania, USA	1	C_{mic}	0 - 37 % increase	Doran et al. (1987)
Frankstone, Victoria, Australia	3	fungi, bacteria	increases	Sivaplan et al. (1993)
SAFS, UC Davis, California, USA	4	C_{mic} (CFE) basal CO_2	~25 % increase increase	Gunapala and Scow (1998)
SAFS, UC Davis, California, USA	7	C_{mic} (CFE) microbial biomass-N SIR diversity (PLFA)	0-55 % increase ~8-50 % increase ~66 % increase similar	Bossio et al. (1998)
DOK, Reckenholz, Switzerland[1]	18	C_{mic} C_{mic}-to-C_{org} qCO_2	similar decrease - 4 % increase similar	Fließbach and Mäder (2000)
Ensmad, Suttgart-Hohenheim, Germany	22	C_{mic} C_{mic}-to-C_{org}	0-32 % increase no difference	Friedel (2000)
Southern Germany, Nine locations	10	C_{mic} C_{mic}-to-C_{org}	~10-15 % increase ~10-15 % increase	Emmerling et al. (2001)
DOK, Reckenholz, Switzerland[2]	21	microbial diversity qCO_2	increase decease	Mäder et al. (2002)
Burgrain, Schweiz	10	C_{mic}	inconclusive	Oberholzer (2004)
SKAL farms in Netherland	3	oligotrophic bacteria basal CO_2	65 % increase 70 % increase	van Diepeningen et al. (2006)
Colle Valle Agricultura, Viterbo, Italy	6-7	C_{mic} C_{mic}-to-C_{org} qCO_2	increase increase decrease	Marinari et al. (2006)
CEFS, Goldsboro, NC, USA	3	C_{mic} basal CO_2	> 50 % increase > 80 % increase	Tu et al. (2006)
CARDC, Wooster, Ohio, USA	4	microbial biomass-N	43 % increase	Briar et al. (2007)
DOK, Reckenholz, Switzerland[2]	21	C_{mic} (CFE) C_{mic}-to-C_{org} dehydrogenase activity basal CO_2 qCO_2	0-43 % increase 30-40 % increase 71-100 % increase no difference 27-30 % decrease	Fließbach et al. (2007)
DOK, Reckenholz, Switzerland[2]	25	bacterial and fungal diversity (PLFA)	increase	Esperschütz et al. (2007)
Parnaiba, Piauí State, Northeast Brazil	2	C_{mic} C_{mic}-to-C_{org} qCO_2	51-121 % increase 60-120 % increase 19-37 % decrease	Araújo et al. (2008)
DOK, Reckenholz, Switzerland[2]	27	C_{mic} (CFE) bacterial-C muramic acid fungal/bacterial ratio ATP	87 % increase 35 % increase 33 % increase 19 % decrease 92 % increase	Joergensen et al. (2010)
NESC, Nafferton, Northeast England	6	free-living N-fixers (qPCR)	decrease	Orr et al. (2011)
Darmstadt trial, Darmstadt, Germany[3]	10	C_{mic} C_{mic}-to-C_{org}	12.5 % decrease 8.5 % decrease	Heinze et al. (2011)
Parnaiba, Piauí State, Northeast Brazil	10	C_{mic} C_{mic}-to-C_{org} qCO_2	400 % increase 11-70 % increase 40 % decrease	Santos et al. (2012)

For this compilation data from the [1]Conventional vs. BIORG, [2]CONMIN vs. BIOORG and [3]INORG vs. FYM plots were chosen for comparison. Microbial parameter: C_{mic} = microbial biomass-C; SIR = substrate induced respiration; C_{mic}-to-C_{org} = % C_{mic} of total C_{org}; qCO_2 = unit CO_2 released per unit C_{mic} (specific respiration); ATP = adenosine triphosphate.

management remained unchanged during the monitoring period (Table 4). This difference in mode of biomass development could not be attributed to a lack of manure application (Table 3) since plots under "MIXED" with no increases had inputs of different types of farm manure in comparison to "STOCKLESS1" with hardly any manure application; however this difference may be attributed to differences in crop residue input. The leading crop under "STOCKLESS1" were legumes (clover grass, field peas), which are crops with humus reproduction, in comparison to cereals/linseed under "MIXED" (Table 2). The latter are crops with humus demand with respect to humus balances (Kasper et al., 2015; Kolbe, 2013 and Table 2). A recycling of 100 % of the grain crop residues and clover grass material in plots under "STOCKLESS1" are a further significant difference with respect to the management under "MIXED" with only 50 % of residue material remaining (Table 3). Accordingly it can be assumed that all six implemented organic farming systems will have a different pace of development towards a new equilibrium. From the earlier studies on organic matter turnover it is known that it can take many decades until a new equilibrium is reached, particularly in those soils with manure application (i.e. Jenkinson et al., 1987; van der Linden et al., 1987).

As mentioned before the parameter C_{mic}-to-C_{org} denotes the availability of C_{org} and nutrients for microbial growth. This intricate relationship between microbial growth and metabolic activity to C:N:P ratios in soils has recently been investigated (Ehlers et al., 2010; Li et al., 2012; Hartman and Richardson, 2013) whereby P again was identified as an important growth promotor. In our field system "DAIRY", the carbon additives in the form of different types of manure applications plus legumes as crop residues seem to supply the soils with sufficient N and P, which enables the microflora to use more carbon for growth in comparison to the starting situation and to the other organic systems, since the % C_{mic} of total C_{org} rose from 2.4 to 2.8 (Table 4). Although these plots lost 8.4 to 25 % P over time, they were plots with the highest C_{mic} and C_{mic}-to-C_{org} increases for ploughland in the year 2008 which indicates these plots still have a sufficient P level. Under controlled laboratory conditions it could be shown that micro-organisms stop growing under carbon surplus if N but moreover P is a limiting factor (Anderson and Gray, 1991). Under such conditions the C_{mic}-to-C_{org} ratio would decrease with time. This can be demonstrated with plots changed to "PIG" land use initially under conventional farming with the highest C_{mic}-to-C_{org} ratio of 3.1 to 4.0. Conversion to organic farming, with respect to the chosen cropping system, was negative since plots lost microbial biomass and the use of C_{org} was sub-optimal since this initially high C_{mic}-to-C_{org} ratio had decreased by 13 % to 27 %.

The microflora has to compete with plants for nutrients. The C:N:P ratio of the micro-environment must be optimal for growth in order to sustain a cell-internal C:N:P: ratio of fungi and bacteria which amounted on average to 10:2:1 under pure culture condition (Anderson and Domsch, 1980) and to 36:5:1 under soil condition (Griffiths et al., 2012). This C:N:P relations and microbial activity can be largely influenced by input and quality of organic matter (Amaral and Abelho, 2016). To evaluate the fate of microbial growth potentials more precisely in organic farming systems, analysis of the nutrient transfer and nutrient status respectively seems necessary. Such an approach was recently attempted for plots under the organic system DAIRY with respect to phosphate (Ohm et al., 2015).

5 Conclusions

After conversion to organic farming the framework conditions of the soils will determine whether or how fast the microflora will respond to the diversity of organic substances entering the soil system. Of major importance seems to be here an optimal C:N:P ratio that organic inputs and management can develop their full potential for enhancing microbial growth and activity with respect to organic matter decomposition. This would necessitate knowledge about the nutrient transfer and how nutrients can be controlled (managed) to avoid nutrient limitations for optimal microbial conditions. Here the C_{mic}-to-C_{org} ratio is a sensitive indicator of nutrient deficits.

Crop rotation systems under conventional management with mineral and organic fertilization correspond to results obtained with organic farming with respect to C_{mic} growth and the C_{mic}-to-C_{org} ratio in our study.

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