Integrated soil quality assessment as an indicator for a successful conversion to organic agriculture

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Abstract

The results of an extensive soil quality assessment on conventionally managed fields were compared with the soil quality on a reference field as a result of a multi-year organic management. Application of soil improving management practices in conventional agriculture will facilitate the conversion to organic agriculture. Inclusion of a ley is a promising practice to increase the organic matter content and sustain soil quality, however, its management might be decisive for reaching that goal. Ca and Mg input by fertilization should be equilibrated, as a factor affecting the Ca:Mg ratio and therefore soil structure. Correct application technique and timing of soil improving fertilization should prevent reduced root growth due to bacterial decomposition activity.

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Introduction

Organic farming sustains soil quality by proper soil management practices, e.g., regular organic fertilization, a broad crop rotation with cover crops and reduced tillage practices. However, awareness of soil quality issues is growing in conventional farming resulting in a more frequent application of soil quality sustaining measures by conventional growers, inspired by neighbouring organically growing colleagues or informed by extension programs. It is likely that conventional farmers who already take care of soil quality have a good chance to be successful in the conversion to the organic production method when triggered by more attractive market conditions for the organic sector. Therefore we made a profound assessment of soil quality on 3 conventional farms that are applying or intend to apply a clear soil quality improving strategy and compared with an organic farm. Because of the soil complexity, our survey focused on all kinds of soil quality aspects.

Material and methods

One organically managed farm participated in the survey with the reference field 3. Three conventionally managed farms participated, i.e., two with one field (fields 1 and 2) and one with two fields (fields 4 and 5). All farms apply some soil improving practices.
Field 1 belongs to a farm that combines horticultural with arable crops. Onions, carrots and potatoes are grown in a rotation with cereals. Ruminant beef production was abandoned 8 years ago. Cover crops are regularly used and soil improving fertilization forms (compost, animal manure, …) are applied before sowing the winter cover crop (e.g., *Tagetes* in 2015). Additionally, mineralfertilization is applied in spring before installing the main crop (potatoes in 2016).

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Mouldboard ploughing (depth < 30 cm) is the main tillage practice. Field 2 was leased land by a conventional dairy farmer till 2014 for the cultivation of maize, with little investment in soil fertility building. Upon acquisition of the land by a vegetable grower, it was ploughed (depth 40 cm) and a ley of Italian ryegrass was installed in the autumn of 2015 (after a black fallow period) as a soil fertility building crop that was grown until spring 2017. The grass was not removed but mulched and cattle slurry was applied after the second mulching, i.e., short before soil sampling. Field 3 had a long history of organic cultivation (conversion of an orchard in 1978, which was installed after deforestation in 1958). Intensive vegetable cultivation started in 1993. Non-inversion tillage was executed in 2014 and 2015, but in spring 2016, the field was ploughed (depth 25 cm) in order to destroy a grass sward installed as a cover crop after cauliflower in 2015 and to incorporate 20 Mg farm yard manure per ha. Fields 4 and 5 belonged to the farm that combines animal and crop husbandry. A vegetable crop sequence is alternated with a ley phase. For field 4, 2016 was the first year that vegetables (headed cabbage) were grown after a ley phase of 10 years. The ley was ploughed in spring 2016 after chemical destruction. A base mineral N dressing was applied at planting (160 kg N ha^{-1}). On field 5, a temporary ley was installed in the autumn of 2014 after ploughing (depth 35 cm) to incorporate the residues of a cauliflower crop. In 2015 the grass was either mowed or grazed, and received cattle slurry once. After a first late cut in 2016, 20 Mg cattle slurry per ha was injected, i.e., shortly before soil sampling.
The 0-20 cm top layer of all fields was sampled under a standing crop in the beginning of August (fields 1 and 2 on 3 August and fields 3-5 on 9 August). At that time the moisture content of the soil was considerably high due to the rainy weather conditions. Based on the Belgian soil classification the dominant texture was light sandy loam except field 3 of which the texture was loamy sand. Each soil profile showed a cambic (B) horizon and they were classified as 'moderately wet' with regard to drainage condition. Inherent soil characteristics were quite similar between fields, which was important for the evaluation of the differences in soil quality related to the applied soil management practices.
Physical soil quality was also visually assessed under the standing crop. The soil was analysed for biological and chemical parameters. Biological assessment was done by i) bacterial counts t1 and t2 according to Rusch (2014) (t1 is in line with the bacterial decomposition activity, whereas t2-t1 is a measure for the 'rhizosphere' activity), ii) phospholipid fatty acids (PLFAs) analysis quantifying different microbial functional groups of the soil food web (non-specific bacteria, gram-positive and gram-negative bacteria, actinomycetes, fungi and mycorrhizal fungi) (Frostegård et al., 1991) and iii) nematode community analysis (Ferris et al., 2001). Nematode communities were characterized and classified according to their trophic level and way of life to evaluate the structure of the soil food web and the disease supressiveness. Considered chemical parameters were total organic C (TOC), total N content (Ntot), pH-KCl, hot water extractable C (HWC) and plant available nutrient reserves (P, Ca, Mg, K) extracted with ammonium lactate.

Results

Visual assessment of physical soil status

On both fields with grass, fields 2 and 5, the soil was seriously compacted in the lower part of the arable layer and had a blue shine due to anaerobic soil condition. In contrast, under the potatoes, celeriac and headed cabbage on fields 1, 3 and 4 respectively, the soil showed a nice crumbly structure.

Chemical parameters

The organically managed field 3 showed the highest soil organic matter level, followed by field 4 which had a 10 year history as pasture land. The other fields had a reasonable content (Table 1). The P status of all fields is above the target zone due to regular application of animal manure and compost. The Ca:Mg ratio was extremely low on fields 2 and 5 and high on field 3, which coincided respectively with very low and high NO_3^- : NH_4^+ ratios (Table 1).

Table 1. Chemical soil characteristics: total C (TOC) and N content (Ntot), pH-KCl, hot water extractable C (HWC) and plant available nutrient reserves (P, Ca, Mg, K); Ca:Mg and NO_3^- : NH_4^+ ratios; measurement values for fields 1-5

Field	TOC %	Ntot %	C:N	pH-KCl	HWC ppm	P	Ca	Mg	K	Ca: Mg	NO_3^-: NH_4^+
						mg per 100 g dry soil					
1	1.9	0.13	14.7	6.5	1131	45	143	21	16	4.1	1.2
2	1.5	0.12	12.8	5.7	1327	23	79	21	10	2.3	0.0
3	3.4	0.22	15.4	6.1	1648	28	210	16	32	8.2	2.9
4	2.3	0.20	11.4	5.9	1925	29	130	39	11	2.0	1.0
5	1.6	0.15	11.0	5.2	1542	23	65	18	19	2.2	0.1

A low NO_3^- : NH_4^+ ratio might be indicative for a lack of aeration causing a hindered nitrification. Lack of aeration was likely to happen in the visually compacted soil in the lower part of the arable layer of fields 2 and 5, along with a high soil moisture content at sampling. Moreover, the compaction can be explained by very low Ca:Mg ratios for both fields. The highest Ca:Mg was found for field 3 which coincides with a high NO_3^- : NH_4^+ ratio, indicative for a high nitrification rate.

Biological parameters

Fields 1 and 3 showed the highest bacterial decomposition activity (t1), whereas fields 4 and 5 showed the strongest 'rhizosphere' (t2-t1) (Table 2). High t1 values reflect the presence of undecomposed organic residues, derived from incorporated *Tagetes* and stable manure in fields 1 and 3, respectively, the decomposition of which might have caused reduced root growth.

Table 2. Bacterial counts according to technique 1 (t1) and technique 2 (t2) of the Rusch test

Field	t1	t2	t2-t1	t2 : t1
1	176	356	180	2.0
2	70	235	165	3.4
3	173	362	189	2.1
4	82	421	339	5.1
5	83	400	317	4.8

HWC seems to be correlated with total microbial biomass as quantified by PLFA analysis (Figure 1). HWC would be the easily available C fraction. PLFA values of specific microbial groups were correlated with values of total microbial biomass (results not shown).

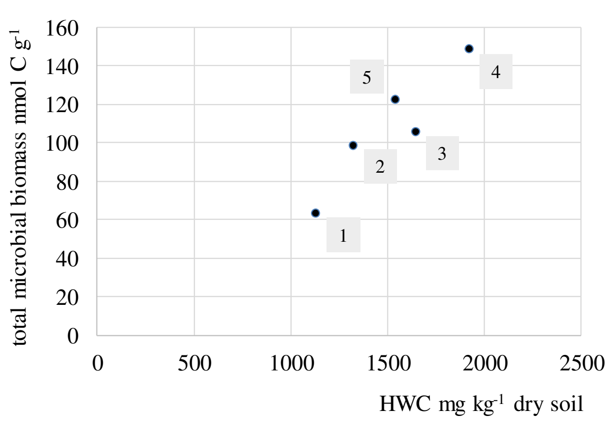

Figure 1. Total microbial biomass quantified by PLFA analyses versus hot water extractable C (HWC) in the 0-20 cm soil layer of fields 1-5

The combined use of an 'enrichment' (EI) and 'structure' index (SI) derived from the classification of the nematodes according to their trophic level and mode of life, pointed out that both fields 3 and 4 showed a recovering soil food web, with the presence of omnivorous and predator nematodes, whereas the other fields showed a more disturbed soil food web, especially field 1 with an extremely low SI (Figure 2).

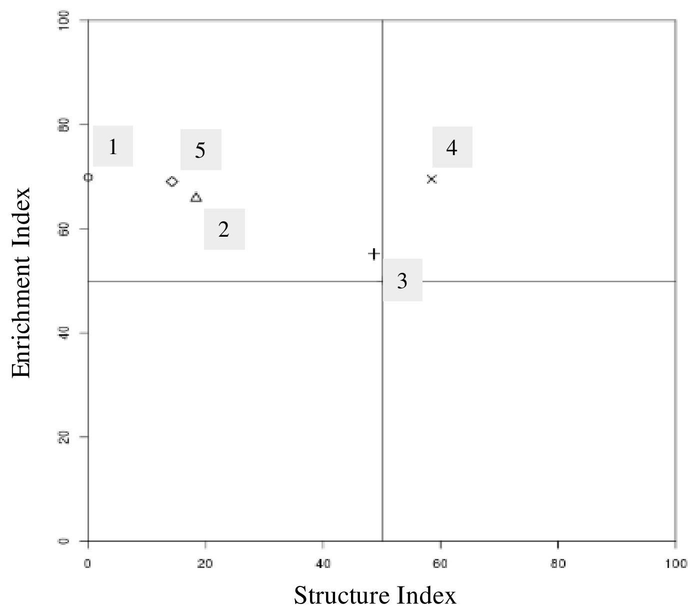

Figure 2. Soil food web analysis based on the nematode community in the 0-20 cm top soil of fields 1-5

Discussion

This investigation shows that soil quality on conventionally managed fields where farmers apply multiple soil improving practices may approach a level comparable with that of an organically managed field over a multi-year time span. Inclusion of a ley is a promising practice to increase the organic matter content and sustain soil quality, however, its management might be decisive for reaching that goal. Ca and Mg input by fertilization should be equilibrated, as a factor affecting the Ca:Mg and therefore soil structure. A proper incorporation technique and application time of stable manure and crop residues should prevent hindrance for root growth due to bacterial decomposition activity. Working on soil quality issues is a big step in advance to conversion to organic agriculture.

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