Microbial biomass and size-density fractions differ between soils of organic and conventional agricultural systems

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Abstract

Agricultural production systems have to combine management practices in order to sustain soil quality and also profitability. We investigated microbial biomass and size-density fractions of soils from a long-term field trial set up in 1978 at Therwil, Switzerland. It compares the economic and ecological performance of organic and conventional agricultural systems. Main differences of the systems were the amount and form of fertiliser as well as the plant protection strategy, whilst crop rotation and soil tillage were the same. Microbial biomass C and N as well as their ratios to the total and light fraction C and N pools in soils of the organic systems were higher than in conventional systems. This is interpreted as an enhanced decomposition of the easily available light fraction pool of soil organic matter (SOM) with increasing amounts of microbial biomass. The role of microbial biomass as a regulator and light fraction organic matter as an indicator of decomposition is discussed. The presented results indicate that labile pools of SOM are distinctly affected by long-term management practices. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Organic farming; Long-term field trial; Microbial biomass; Light fraction; Particulate organic matter; Soil quality

1. Introduction

Organic farmers do not use synthetic fertilisers and pesticides and aim at keeping a closed nutrient cycle on their farms, striving to protect environmental quality and to enhance beneficial biological interactions and processes (Reganold et al., 1993; Vandermeer, 1995). Plant production in organic farming mainly depends on nutrient release as a function of mineralisation processes in soils. An active soil microflora and a considerable pool of accessible nutrients, therefore, is an important priority in organic farming. Fertilising the soil rather than the plant is an organic farmers’ goal to assure sufficient nutrient mineralisation to meet his economic needs.

Plant growth is mainly determined by N availability.

N mineralisation and immobilisation are soil microbial processes governed by C availability and are supposed to be linked closely to “active” fractions of soil organic matter (SOM) (Hassink, 1994). Organic matter cycling models often base on these SOM-pools with different turnover times (Jenkinson et al., 1987; Parton et al., 1987; Verberne et al., 1990). In this concern size and density fractionation approaches were often used to determine the amount and composition of SOM associated with size classes (Christensen, 1992). Janzen et al. (1992) identified labile (“active”) SOM fractions by densiometric techniques, which responded much faster to management changes than total SOM. Hassink et al. (1997) used a combined size–density fractionation technique and assumed that the amount of macroorganic matter (>150 μm) is controlled by soil management, while the amount of C associated with clay and silt particles is controlled by soil texture. They concluded that light fraction organic matter is sensitive to changes in C-input and can be used as an early indi-
cator of management changes. However, there is still reason to doubt that size–density fractionation techniques yield the “active” fraction as has been concluded by Magid et al. (1996). More recently Magid et al. (1997) applied a size density fractionation as a less artificial alternative to the litterbag approach in decomposition studies. Management effects of organic and conventional farming practice were found to affect total C_{org} as well as light fraction SOM (Wander and Traina, 1996) in the Rodale farming systems trial (Kutztown, USA), which includes a conventional and two organic systems, one based on legumes and one on manure as nutrient input.

Reeves (1997) reviewed SOM dynamics in long-term continuous cropping system trials, emphasising that soil organic matter tends to decrease in most studies and can only be preserved by ley rotations, with their reduced tillage frequency. System effects of organic and conventional agricultural farming practice on soil biota were reviewed by Mäder et al. (1996) comparing four different long-term field trials at Darmstadt, Germany (Bachinger, 1996), Järna, Sweden (Petterson et al., 1992), Kaisheim, Germany (Beck, 1991) and Therwil, Switzerland. In any case soil microbial activity (dehydrogenase, catalase) in the organic farming treatments were 30–70% and in the bio-dynamic 40–90% higher than in respective soils receiving mineral fertiliser only. In the Rodale farming systems trial, however, no significant effect on total soil biomass, based on phospholipid fatty acids was found (Wander et al., 1995).

The number of field trials comparing organic and conventional systems is limited, moreover there are only a few investigations of system effects on soil microbial properties on biological and conventional farms (Reganold et al., 1993; von Lützow and Ottow, 1994; Murata and Goh, 1997). Comparing microbial biomass and diversity on paired organic and conventional farms at three grassland sites in New Zealand, Yeates et al. (1997) found higher C_{mic} in two cases but once a lower C_{mic} at a loamy site in organic compared to conventional management. Nevertheless, there seems to be a trend for higher microbial biomass and biological activity in arable organically-managed soils compared to conventionally managed soils also on the farm level. Comparisons on the farm level have to cope with site heterogeneity, different management practices and also the farmer’s skill, which may not always result in a higher fertility on organic farms. This is a striking argument for comparing system effects under field trial conditions, where site heterogeneity is less critical.

Under the assumption that light fraction organic matter serves as an indicator and microbial biomass as the regulator of decomposition we hypothesise that soils with higher amounts of biomass decompose organic matter more rapidly thus reducing the amount of light fraction organic matter. We tested this functional relationship by measuring microbial biomass and size density fractions of SOM in soils of a long-term field trial where organic and conventional farming systems have been compared for 18 yr.

2. Materials and methods

2.1. The field experiment

In 1978 the DOC (bio-Dynamic, bio-Organic, Conventional) field experiment comparing two organic and two conventional cropping systems was set up at Therwil in the vicinity of Basle, Switzerland, by the Swiss Federal Research Station for Agroecology and Agriculture (Zurich-Keckenholz) in co-operation with the Research Institute of Organic Agriculture (Frick). The soil is a haplic luvisol (sL) on deep deposits of alluvial loess. The climate is rather dry and mild with a mean precipitation of 785 mm yr^{-1} and an annual mean temperature of 9.5 °C. The four cropping systems mainly differed in fertilisation strategy and plant protection (Table 1). Crop rotation (potatoes, winter wheat 1, beet roots, winter wheat 2 and three years of grass clover) and soil tillage were identical for all treatments (Besson and Niggli, 1991).

All systems with manure amendment were performed at two fertilisation intensities, corresponding to 0.7 and 1.4 livestock units ha^{-1}. The bio-dynamic (BIO-DYN) and the organic (BIO-ORG) systems received only organic fertiliser, whereas organic and mineral fertilisers were applied in the conventional (CONFYM) system (Table 1). Another plot was left unfertilised during the first crop-rotation, but was then converted to a conventional treatment with mineral fertiliser only (CONMIN) and a control plot remained unfertilised (NOFERT), but was amended with bio-dynamic preparations. The biological systems (BIO-DYN and BIO-ORG) received 45–69% of the plant available nutrients (NPK) that were applied to the conventional systems (CONFYM and CONMIN) (Niggli et al., 1995).

On an average over the whole field trial period, crop yields in the organic systems were 14–16% lower than in the respective conventional system. The yield response to organic vs. conventional management was more pronounced with potatoes (30%) and red beets (24%) than with the grass–clover ley (19%) and winter wheat (11%) (Table 2). These differences may be ascribed primarily to the amount of nutrients applied: during the first 14 yr of the trial, the total N, P and K supply in the organic systems was lower than in the conventional system, by 25, 40 and 50% respectively. The organic fertilisation was performed with system-
Table 1
Main differences of the DOC farming systems

<table>
<thead>
<tr>
<th>Treatments</th>
<th>bio-dynamic</th>
<th>bio-organic</th>
<th>conventional</th>
<th>mineral NPK</th>
<th>unfertilised</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fertilisation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FYM type</td>
<td>FYM and slurry (FYM)</td>
<td>FYM and slurry</td>
<td>FYM and slurry 0.7</td>
<td>NPK fertiliser</td>
<td>—</td>
</tr>
<tr>
<td>and slurry 0.7 or 1.4 livestock units</td>
<td>or 1.4 livestock units + NPK fertiliser</td>
<td>20</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>FYM C-to-N ratio</td>
<td>13</td>
<td>18</td>
<td>20</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>FYM preparation</td>
<td>composted</td>
<td>rotted</td>
<td>stacked</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>FYM age</td>
<td>8-12 months</td>
<td>3 months</td>
<td>4-8 months</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>Plant protection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weed control</td>
<td>mechanical</td>
<td>mechanical</td>
<td>mechanical and herbicidesa</td>
<td>mechanical and herbicidesa</td>
<td>mechanical</td>
</tr>
<tr>
<td>Disease control</td>
<td>indirect methods</td>
<td>indirect methods</td>
<td>chemicalb</td>
<td>chemicalb</td>
<td>chemicalb</td>
</tr>
<tr>
<td>Insect control</td>
<td>plant extracts, bio-control</td>
<td>plant extracts, bio-control</td>
<td>chemicalb</td>
<td>chemicalb</td>
<td>chemicalb</td>
</tr>
<tr>
<td><strong>Special treatments</strong></td>
<td>biodynamic preparationsb</td>
<td>—</td>
<td>plant growth regulators</td>
<td>plant growth regulators</td>
<td>biodynamic preparationsb</td>
</tr>
</tbody>
</table>

a Herbicides (1–2 treatments yr⁻¹) and fungicides (2–3 treatments yr⁻¹) according to threshold values, CCC was applied routinely to winter wheat. Pest control was necessary regularly in potatoes and rarely in winter wheat.

b The bio-dynamic preparations (P) consist of the following: P 500: cow-manure fermented in a cow horn; P 501: silica fermented in a cow horn, which were amended at rates of 250 and 4 g ha⁻¹ respectively. Composting additives are yarrow flowers (P 502, Achillea millefolium, L.), camomile flowers (P 503, Matricaria recutita, L.), stinging nettle (P 504, Urtica dioica, L.), oak bark (P 505, Quercus robur, L.), dandelion flowers (P 506, Taraxacum officinale, Wiggers) and valerian flowers (P 507, Valeriana officinalis, L.). A decoct of shave-grass (Equisetum arvense, L.) is applied once during vegetational growth to wheat and potatoes as a protective agent against plant diseases at rates of 1.5 kg ha⁻¹. For further details see Reganold and Palmer (1995) or Koepf et al. (1976).
specific manure types and the fertilisation schedule in the organic systems involved small and more frequent manure applications than in the conventional system, where the total amount of manure was split to be applied to red beets and potatoes only. C-to-N ratios of manure and slurry applied to potatoes and winter wheat the year before soil sampling averaged 13 for the bio-dynamic, 18 for the bio-organic and 20 for the conventional system.

Plant protection of the bio-dynamic and bio-organic systems was conducted according to the respective guidelines (Lampkin, 1990; Reganold and Palmer, 1995). Pesticides in the conventional systems (CON-FYM, CONMIN) were mainly applied with respect to economic thresholds (integrated plant protection). Plant protection in the unfertilised treatment was the same as in the bio-dynamic system.

The experiment is designed as a Latin square with four replicates. Single plot size is 5 m by 20 m. The experiment was conducted close to agricultural farming practice and in order to ascertain this link, advisory farmer groups were established for each system.

Soil samples were taken in March 1996 as a bulked sample from 16 cores of 3 cm dia and 20 cm depth (plough layer) of each of the four field replicates under winter wheat. Soils were sieved (2 mm) and kept at 4°C until they were analysed. The pH of dried samples (60°C, 24 h) was measured in a soil suspension with 0.1 M KCl (1:10 w/v). Total organic C and total N were determined in a CHN-Analyzer (LECO CHN-1000, Michigan, USA).

### 2.2. Soil microbial biomass

Soil microbial biomass C (Cmic) and N (Nmic) was estimated by chloroform-fumigation-extraction (CFE) according to Vance et al. (1987). CFE was done on 20 g (dry matter) subsamples that were extracted with 80 ml of a 0.5 M K2SO4 solution. Total organic C (TOC) in soil extracts was determined by infrared spectrometry after combustion at 850°C (DIMA-TOC 100, Dimatec, Essen, Germany). Total N was subsequently measured in the same sample by chemoluminescence (TNb, Dimatec, Essen, Germany). Soil microbial biomass was then calculated according to the formula:

\[
C_{mic} = \frac{E_C}{k_{EC}}
\]

\[
E_C = (\text{TOC in fumigated samples-TOC in control samples}).
\]

\[
k_{EC} = 0.45 \quad \text{(Joergensen and Mueller, 1996a)}.
\]

\[
N_{mic} = \frac{E_N}{k_{EN}}
\]

\[
E_N = (\text{N in fumigated samples-N in control samples}).
\]

\[
k_{EN} = 0.54 \quad \text{(Joergensen and Mueller, 1996b)}.
\]

### 2.3. Soil respiration and qCO₂

Respiration was measured as CO₂ evolution according to Jäggi (1976). Soil samples were conditioned for 7 d at 22°C and 40–45% water holding capacity. CO₂ trapped in NaOH over 24 h was then determined titrimetrically. qCO₂ was calculated by dividing hourly respiration rates by Cmic.

### 2.4. Size density fractionation

Density fractionation was performed according to Meijboom et al. (1995). 400 g (dry matter) of soil was wet sieved through a 150 μm stainless steel sieve. Fine soil particles, clay and silt as well as fine organic material were removed by a gentle stream of tap water, until the water outflow was clear. The remainder on the sieve was washed into a bucket where the material was swirled in about 1 l of water. The light dispersed
material was then decanted into a fractionation sieve (150 μm nylon mesh). This procedure was repeated several times to obtain all the organic material. The mineral particles at the bottom of the bucket were discarded. The organic material retained was defined as particulate organic matter (POM).

Fractionation started with putting the fractionation sieve into Ludox (Dupont) of a density of 1.13 g cm\(^{-3}\). The content was mixed with a spatula and left to separate distinctly into a floating layer and a sediment. After about 10 min the light fraction floating on the surface was collected with a small sieve and washed into a beaker with demineralised water. Mixing and separation was repeated several times until no organic material was visible on the surface. The fractionation sieve was then taken out and put into Ludox of a density of 1.37 g cm\(^{-3}\). The remaining organic material separated into a heavy, sedimenting and an intermediate, floating fraction. The material was washed twice with demineralised water, transferred on filter papers and dried at 60°C for 24 h. The dried organic material was ground (Retsch, MM2224) and analysed for C and N (CHN-1000, LECO).

2.5. Data calculation and statistics

All data presented are the mean of four field replicates, each composed of at least three replicate measurements. A two-way anova (JMP, SAS Institute, Cary, NC) for the manured plots only, was performed with treatment, intensity and their interaction as model effects. With significant effects a Tukey-Kramer HSD (honestly significant difference) test was performed to compare all pairs at \( P = 0.05 \).

3. Results

3.1. Soil reaction and soil organic matter

In the year before the beginning of the field experiment in 1978, pH (6.3) and soil organic C (1.7%) in the plots of the field trial varied only a little (<5%) (Alföldi et al., 1993). After 18 y the differences obtained in the soils of the field trial treatments were therefore due to the management steps of the respective systems (Table 3). pH differences were significant between the bio-dynamic and the unmanured treatments. The lowest pH was found in the mineral treatment (CONMIN).

Compared to the beginning of the experiment in 1979, \( C_{\text{org}} \)-values in the unmanured systems decreased by 22%, in the manured systems at low intensity by 13% and by 8% at high intensity. Total N showed the same trend, but neither treatment nor intensity effects were significant. The C-to-N ratio of soil organic matter was hardly affected by the different systems.

3.2. Soil microbial biomass

Biomass C (\( C_{\text{mic}} \)) and N (\( N_{\text{mic}} \)) were significantly affected by the long-term management as well as by its intensity. \( C_{\text{mic}} \) and \( N_{\text{mic}} \) in the bio-dynamic systems at both intensities were significantly higher than in the unmanured (NOFERT, CONMIN) and the conventional treatments at low intensity (Fig. 1). \( C_{\text{mic}} \) in the bio-dynamic plots at low fertiliser intensity was 64% and at high intensity 45% higher than in the respective conventional plots with manure amendment. In the bio-organic plots relative differences to the conventional treatments were 8 and 17% respectively. No effect on microbial biomass was obtained by the mineral fertiliser applied in the CONMIN-system, when compared to the unfertilised.

The microbial C-to-N ratio (\( C_{\text{mic}}/N_{\text{mic}} \)) was significantly affected by the fertilisation intensity (Table 5). With no manure \( C_{\text{mic}}/N_{\text{mic}} \) showed the highest values, whilst differences between the manured systems showed the ranking BIO-DYN < BIOORG < CON-FYM at both intensity levels.

The \( C_{\text{mic}} \)-to-\( C_{\text{org}} \) ratio as well as the \( N_{\text{mic}} \)-to-N ratio were significantly affected by the systems as well as by the intensity (Table 4). At both intensity levels the bio-dynamic system showed higher values than the bio-organic and the conventional system. The latter did not differ from the unmanured systems. The metabolic quotient for CO\(_2\) (\( q_{\text{CO2}} \)) was affected by system and intensity. Among the manured systems, the \( q_{\text{CO2}} \) in soils from the bio-dynamic system was lower than in the conventional and the bio-organic system. With higher intensity, \( q_{\text{CO2}} \) was lower.

3.3. Particulate organic matter (POM) fractions

The amount of particulate organic matter obtained varied between 1.2 and 1.8 g kg\(^{-1}\) soil corresponding to an amount of 300–450 mg C kg\(^{-1}\) soil, which made up 2–3.5% of total soil organic C. C-concentration in the respective density fractions averaged 37% in the light fraction, 32% in the intermediate and 10–17% in the heavy fraction, indicating that mineral soil components were becoming increasingly present with increasing density. Significant treatment effects were found with light and intermediate fractions but not with heavy fraction material (Fig.2a–c). C in the light fraction of the conventional soils, both with or without manure, was higher than in the bio-dynamic and the bio-organic soils. Intermediate fraction C was higher in the bio-dynamic soils than in all the other treatments. The two intensities in the manured treat-
ments did not show a significant effect on fractions of POM-C.

Nitrogen in POM varied between 15 and 25 mg kg\(^{-1}\) corresponding to 0.9–1.9% of total soil N. N content in the intermediate fraction was significantly higher than in the heavy fraction (data not shown). Heavy fraction N content was higher at high manure intensity (Fig. 2f). Intermediate fraction N in the bio-dynamic soils was higher than in the other soils of the experiment (Fig. 2e). Light fraction N was affected neither by treatment nor by intensity.

C-to-N ratios of density fractions over all treatments in the light fraction (22.3) were higher than in the intermediate fraction (18.8) and in the heavy fraction (20.6). Compared to the whole soil, the C-to-N ratios of the density fractions were distinctly wider. The effect of the systems was significant but not the one of fertilisation intensity. Among all the fractions, C-to-N ratios were smallest in the bio-dynamic soils. Light fraction C-to-N ratios in the conventional soils at low intensity were significantly higher than in the bio-organic, whilst in the intermediate fraction the difference between bio-organic and bio-dynamic was significant. The latter was also found at high intensity. For the heavy fraction a significant interaction of treatment and intensity was found for the C-to-N ratio, indicat-
ing a decrease with intensity in the bio-dynamic and the conventional soils whilst in the bio-organic an increase was found (Table 5).

### 4. Discussion

Agricultural production systems comprise a variety of management steps. The soil integrates the sum of these influences, but when looking at the performance of the whole system it is hardly possible to track on effects of single factors, like fertilisation, crop rotation, or plant protection. Soil organic matter fluctuates according to the long-term plant cover or land use. Soil microbial biomass as well as density fractionates of SOM are regarded as active pools of the total SOM. They are supposed to react quickly to changes in land use and management measures, whilst passive pools of soil organic matter are more stable and change slowly. In SOM modelling they are involved as pools of available and recalcitrant C and N.

It is necessary to bear in mind that all the systems of the DOC field experiment are performed with respect to official guidelines, therefore the conventional systems cannot be considered environmentally harmful. Moreover, the main systems are fertilised organically and comprise a large variety of crops in the rotation, which are measures that favour soil fertility. Therefore it is important to note that all the systems compared in this trial are already on a high level of sustainability.

#### 4.1. System effects on soil microbial biomass and activity

Soil microbial biomass and microbial activity were distinctly affected by the agricultural management measures (amount and quality of manure and fertiliser applied annually and strategy of plant protection). An increase of both microbial biomass and average crop yield was found as a response to the two intensity levels. This effect was similar for all manured systems,

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Intensity</th>
<th>C\textsubscript{mic}/C\textsubscript{org} ratio (mg g\textsuperscript{-1})</th>
<th>N\textsubscript{mic}/N\textsubscript{t} ratio (mg g\textsuperscript{-1})</th>
<th>qCO\textsubscript{2} (μg CO\textsubscript{2}-C mg C\textsubscript{mic} h\textsuperscript{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfertilised</td>
<td>–</td>
<td>14.4</td>
<td>19.5</td>
<td>1.44</td>
</tr>
<tr>
<td>Mineral NPK</td>
<td>–</td>
<td>13.9</td>
<td>20.0</td>
<td>1.30</td>
</tr>
<tr>
<td>Bio-dynamic</td>
<td>low</td>
<td>21.0</td>
<td>31.6</td>
<td>0.91</td>
</tr>
<tr>
<td>Bio-organic</td>
<td>low</td>
<td>17.2</td>
<td>24.4</td>
<td>1.29</td>
</tr>
<tr>
<td>Conventional</td>
<td>low</td>
<td>14.3</td>
<td>20.9</td>
<td>1.33</td>
</tr>
<tr>
<td>Bio-dynamic</td>
<td>high</td>
<td>22.5</td>
<td>37.1</td>
<td>0.81</td>
</tr>
<tr>
<td>Bio-organic</td>
<td>high</td>
<td>18.2</td>
<td>27.4</td>
<td>1.11</td>
</tr>
<tr>
<td>Conventional</td>
<td>high</td>
<td>17.5</td>
<td>27.0</td>
<td>1.07</td>
</tr>
</tbody>
</table>

LSD (p = 5% sign. -level) 5.4 9.5 0.64

treatment 0.0001 0.0013 0.0157
intensity 0.0098 0.0028 0.0442

#### Table 5

C-to-N ratios of microbial biomass, light fraction, intermediate fraction and heavy fraction organic matter in soils of the DOC field trial. Tukey–Kramer LSDs for all treatments and two way anova significance levels for the manured plots are presented in the last rows (n = 4, ns = not significant).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Intensity</th>
<th>Microbial biomass</th>
<th>Light fraction</th>
<th>Intermediate fraction</th>
<th>Heavy fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfertilised</td>
<td>–</td>
<td>7.32</td>
<td>24.3</td>
<td>19.8</td>
<td>20.6</td>
</tr>
<tr>
<td>Mineral NPK</td>
<td>–</td>
<td>7.05</td>
<td>22.6</td>
<td>18.8</td>
<td>20.4</td>
</tr>
<tr>
<td>Bio-dynamic</td>
<td>low</td>
<td>6.42</td>
<td>19.7</td>
<td>16.4</td>
<td>19.0</td>
</tr>
<tr>
<td>Bio-organic</td>
<td>low</td>
<td>6.78</td>
<td>23.2</td>
<td>20.2</td>
<td>22.2</td>
</tr>
<tr>
<td>Conventional</td>
<td>low</td>
<td>6.97</td>
<td>24.1</td>
<td>19.7</td>
<td>21.8</td>
</tr>
<tr>
<td>Bio-dynamic</td>
<td>high</td>
<td>5.95</td>
<td>20.2</td>
<td>16.6</td>
<td>17.5</td>
</tr>
<tr>
<td>Bio-organic</td>
<td>high</td>
<td>6.45</td>
<td>22.3</td>
<td>20.0</td>
<td>24.2</td>
</tr>
<tr>
<td>Conventional</td>
<td>high</td>
<td>6.66</td>
<td>22.2</td>
<td>19.0</td>
<td>18.7</td>
</tr>
</tbody>
</table>

LSD (p = 5% sign. -level) 0.90 5.4 3.6 4.21

treatment ns 0.0430 0.0026 0.0609
intensity 0.0262 ns ns ns
indicating a similar situation of factor limitation for plant as well as for microbial biomass growth. Exclusively mineral fertilisation and chemical plant protection also had a distinct effect on crop yield, however, no positive effect on microbial biomass. The positive effect of compost on microbial biomass without a considerable yield response, compared to the bio-organic system, suggests a strong influence of stabilised compost-derived organic matter. Considering the reported differences in average annual amendment rates, composted manure seems to be more effective with respect to microbial biomass build up than uncomposted manure. However, during the composting process a considerable part of the original material is subject to decomposition and transformation to more recalcitrant compounds. The organic matter loss during composting has been accounted for in the manure application rate that corresponds to the same amount of livestock units.

No data are available on root development and turnover. Especially under situations of different degree of water and nutrient availability root development may have been significantly affected. It has been shown earlier that root turnover of organically grown wheat was enhanced compared to integrated production (Schmid et al., 1997), which may result in a greater C-input to soils of organic systems even at lower above ground biomass amounts.

Single management measures are proven to enhance soil fertility: McGill et al. (1986) reported on a distinctly higher biomass in a 5 yr crop rotation with clover-grass compared to a 2 yr rotation, as well as distinct effects of manure compared to mineral fertiliser application in a 50 yr old field trial. Hassink et al. (1991) found Cmic to be 25% higher in a reduced-input than in a conventional reclaimed polder soil, due to large differences in organic matter input. Microbial biomass was found to be a sensitive indicator of soil disturbance by tillage (Carter, 1986; Salinas-Garcia et al., 1997) and crop rotation vs. monoculture (Anderson and Domsch, 1989).

Differences in $q\text{CO}_2$ are often discussed as a reaction to stress or different community structure. The metabolic efficiency of a microbial community is supposed
to be reflected by their specific respiration rate. For the current study, δCO₂ was lower in organic compared to conventional soils and since the substrate use diversity in organic soils has been found to be higher than in conventional ones (Fließbach and Mäder, 1997), the hypothesis that a more diverse community has a higher metabolic efficiency is supported by our data.

Under steady state conditions, the Cmic-to-Nmic ratio of arable soils is assumed to vary only in a small range. This may be due to the fact that only a minor part (10%) of the microbial biomass is actively taking part in the metabolic process (Jenkinson, 1988). Therefore no evidence seems to exist for variable C-to-N ratios due to the physiological state of a community. The observed Cmic-to-Nmic ratios in our field trial soils, suggest differences in the microbial community structure or the fungal-to-bacterial ratio. With increasing amount of manure the Cmic-to-Nmic ratio decreased suggesting an increasing bacterial biomass fraction. Differences between the systems at the same intensity level were little, but tended towards lower values in the bio-dynamic plots compared to the conventional plots. This may be interpreted as an effect of the C-to-N ratios of the different manures, that were in the same order. If mineral fertiliser N was included in the calculation, the C-to-N ratio of fertilisers in the conventional system would be reduced. Mineral N seems to affect the Cmic-to-Nmic ratio only to a minor extent, when comparing the unfertilised and the mineral fertiliser system.

In our field trial the Cmic-to-Corg ratio was significantly affected by the agricultural systems. The bio-dynamic systems at both intensity levels showed higher values than the two unmanured systems and the conventional system with low manure intensity (see Table 4). Both crop rotation and manure effects were found to be significant factors for an increase in the Cmic-to-Corg ratio based on several experimental sites in Europe and North America (Anderson and Domsch, 1989; Insam et al., 1989). Anderson and Domsch (1989) speculated that the higher Cmic-to-Corg ratio in their crop rotation plots as compared to monoculture systems was a result of a higher efficiency of organic matter utilisation for microbial growth, which they attributed to a more complex organic matter input. This explanation may also be suggested for our field trial systems, however, as a result of manures of different maturity or the direct or indirect effects of plant protection measures. Von Lützow and Ottow (1994) investigated microbial biomass in soils from conventional and bio-dynamic farms. Even though they compared soils under different crops, they found higher Cmic-to-Corg and Nmic-to-Nt ratios on bio-dynamic farms, which is confirmed by our results. In accordance with Murata and Goh (1997) the authors suggest the Nmic-to-Nt ratio to be a more sensitive indicator of soil fertility as affected by agricultural systems than Cmic or the Cmic-to-Corg ratio, whereas our results do not explicitly confirm their statements.

It may be concluded from our results that the amount, activity and composition of microbial communities are affected by the agricultural systems and their intensity. Organic systems are supporting soil quality because (1) microorganisms are utilising the available resources more economically (which means rather for growth than for maintenance), as indicated by a lower δCO₂ and (2) a higher microbial biomass indicates better conditions within the soil organic matter which may contribute to nutrient mineralization and temporary storage of potentially leachable elements.

4.2. Relations between density separates and microbial biomass

Light fraction organic matter comprises mainly freshly added organic material from plant debris and manure (Christensen, 1992). Changes in this fraction were found to reflect the decomposition of plant litter, as it appears to be the fraction that remains undecomposed (Mueller et al., 1998). At a certain set point after incorporation of organic matter to the soil, the light fraction can be considered as the residual fraction inaccessible to decomposition, due to its quality or due to the inability of the decomposer community to further degrade it. Magid et al. (1997) described a rapid decrease of light fraction organic matter (ρ < 1.4 g cm⁻³) in the first 4 months after incorporation of rape straw, followed by a slow decrease, whilst heavy fraction organic matter was hardly affected. The latter was therefore considered to be native organic material with a low decay rate. We did not follow the time course of density fractions but 7 months after potato harvest it can be assumed that the fast initial decomposition process has ceased. Nevertheless, we found a positive correlation of light fraction organic matter with the yield of the preceedingly harvested potatoes (r² = 0.57), whilst the two heavier fractions were hardly affected (Fig. 3). We were not able to account for the actual amount of crop residues entering the soil since no data were available on plant residues, root biomass and turnover. There is evidence, however, that roots growing under relative water deficiency and N limitation have an increased root turnover and a larger rooting system (Schmid et al., 1997). Therefore the correlation of light fraction material to potato yield as an indicator of crop residues entering the soil may be biased, due to a different harvest index in organic and conventional agriculture.

C- and N-pools in the light fraction were highest in the conventional and the mineral treatment soils and
showed lowest values in the bio-dynamic, bio-organic and unfertilised treatment (Figs. 2a and d). Light fraction C and N showed a weak but significant correlation with Cmic and Nmic, respectively, whereas intermediate and heavy fraction C and N were positively correlated. This observation suggested to calculate the quotient of microbial biomass-to-light fraction material, which may serve as an indicator of the quality of recently-added organic material to build-up and maintain microbial biomass (Table 5). A significant role of microbial biomass in decomposition of light fraction organic matter may be confirmed: a smaller part of light fraction organic matter seems to be microbially accessible at low biomass contents, whilst a larger biomass decomposed light fraction material to a higher extent. Accordingly, light fraction organic matter may serve as an indicator of the activity of decomposer organisms in soils. Intermediate and heavy fraction organic matter was positively correlated with Cmic and may thus indicate that Cmic is included in these fractions, or plays a role in their origin (Table 6).

According to Magid et al. (1996) litter entering the light fraction (ρ < 1.13) disappeared almost completely during 100 d, whilst considerable amounts were still detectable in the heavier fractions. Differences in light fraction organic matter may therefore reflect its accessibility to microbial attack. With regard to the great differences in light fraction organic matter in our field trial soils the decomposition and microbial incorporation of added plant material was distinctly greater in the bio-dynamic soils than in the conventional (Fließbach et al., submitted). We conclude therefore that the different light fraction quantities in our field trial soils reflect the ability of the decomposer community to use it as a substrate.

With regard to the composition of the density fractions we expected to find a decrease in C-to-N ratio with increasing density as has already been stated (Hassink, 1995). However, the intermediate and heavy fraction in our soils had almost the same C-to-N ratio, whilst only the light fraction was larger. Nonetheless, we found distinct treatment effects on C-to-N ratios with all density separates, where smallest ratios were found with the bio-dynamic system. This might reflect the system effect on organic matter quality, probably as an effect mainly of the different manure qualities. Even without a prior size fractionation Wander and Traina (1996) found light (ρ < 1.7) and heavy fraction C-to-N ratios to be significantly affected by organic and conventional management practice in their farming systems trial, which is supported by our results.

The long-term management according to organic and conventional farming practice resulted in considerable changes in “active” SOM pools whilst total SOM was little affected. Active SOM-pools like microbial biomass and light fraction SOM are indicating system induced changes early and seem to be inversely correlated. However, more research is needed to clarify this
functional relationship and to quantify accessible SOM pools and their implications on soil fertility and plant nutrition.

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References


Table 6

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Intensity</th>
<th>C_{mic}/light fraction C</th>
<th>N_{mic}/light fraction N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfertilised</td>
<td>–</td>
<td>0.70</td>
<td>2.36</td>
</tr>
<tr>
<td>Mineral NPK</td>
<td>–</td>
<td>0.64</td>
<td>2.03</td>
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<tr>
<td>Bio-dynamic low</td>
<td>low</td>
<td>1.87</td>
<td>5.70</td>
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<tr>
<td>Bio-organic low</td>
<td>low</td>
<td>1.39</td>
<td>4.83</td>
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<tr>
<td>Conventional low</td>
<td>low</td>
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<td>2.81</td>
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<tr>
<td>Bio-dynamic high</td>
<td>high</td>
<td>2.27</td>
<td>7.69</td>
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<tr>
<td>Bio-organic high</td>
<td>high</td>
<td>1.54</td>
<td>5.24</td>
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<tr>
<td>Conventional high</td>
<td>high</td>
<td>1.13</td>
<td>3.73</td>
</tr>
</tbody>
</table>

LSD (p = 5% sign.-level) 0.86 2.93

Treatment ns ns

Intensity ns ns


