Soil organic matter alterations by short-term composted coffee pulp waste: evidence from pyrolysis-field ionisation mass spectrometry

Bekele Eshetu*, Kai-Uwe Eckhardt* and Peter Leinweber*

Abstract

This study investigates the impact of compost from coffee pulp waste on the composition of soil organic matter (SOM) under controlled laboratory conditions. Compost samples were collected after the thermophilic, mesophilic and the final phase and an equivalent of 48 t ha⁻¹ was added to samples of a tropical Nitisol. The soil-compost-mixtures were incubated aerobically for 14 weeks. At the end of incubation the Corg concentrations and the total ion intensities of pyrolysis-field ionization mass spectrometry (Py-FIMS) were larger in compost treatments than in the control. Despite of similar initial organic Corg and Nt contents among compost amended treatments, less organic C was mineralized following the application of compost from the thermophilic than from later composting phases. The SOM in the soil that received the "thermophilic" compost contained significantly higher proportions of carbohydrates, heterocyclic/nitrilic N-compounds, peptides, sterols and n-fatty acids than the other amended soils. Temperature-resolved volatilization curves for carbohydrates, N-compounds and peptides showed that the enriched compounds covered a wide range of thermal stability. In conclusion, the compost from the thermophilic phase had the best effect in terms of biologically labile C sequestration and stabilization of native organic C in a clay-rich tropical Nitisol. If confirmed for other composts and soils, this may have also considerable economic implications because the time period of composting can be shortened.

Keywords: compost, soil organic matter, coffee pulp waste, soil carbon sequestration, molecular composition

Zusammenfassung

Einfluß kompostierter Kaffeefruchtfleisch-Abfälle auf die organische Bodensubstanz: Untersuchungen mit Pyrolyse-Feldionisation Massenspektrometrie


Schlüsselwörter: Kompost, organische Bodensubstanz, Kaffeefruchtfleisch-Abfall, Kohlenstoffspeicherung, molekulare Zusammensetzung

* University of Rostock, Soil Science, Justus-von-Liebig-Weg 6, 18051 Rostock, Germany

Contact: peter.leinweber@uni-rostock.de
1 Introduction

The application of compost to soil has received much attention as an environmentally favorable strategy to use the increasing amount of organic waste and to improve the soil organic matter (SOM) status of agricultural land (Lal, 2004; Weber et al., 2007; Bustamante et al., 2010). Compost application to increase the quantity and improve the quality of SOM is particularly important in strongly weathered tropical soils to overcome the degradation of SOM and improve the soil carbon (C) sequestration (Zech et al., 1997; Lal, 2002, Rivero et al., 2004; Bruun et al., 2010). Studies done by Leifeld et al. (2002), Spaccini et al. (2009) and Eshetu et al. (2012) clearly showed quantitative increases as well as improvements in the SOM quality following compost application to sandy or loamy soils. The effects of compost on composition and stability of SOM depend on various factors including the quality of compost, compost interactions with microbial enzyme systems and mineral soil surfaces (Zech et al., 1997; González-Vila et al., 1999; Grandy and Neff, 2008; Stewart et al., 2011).

Previous research showed that compost application to soil modifies the chemical, physical and biological properties of SOM (Nardi et al., 2004; Adani et al., 2007; Lima et al., 2009). The addition of compost to soil reduced the mineralization of labile compounds of SOM (Fortuna et al. 2003; Piccolo et al., 2004) and increased the humic acid (HA) over the fulvic acid (FA) proportions (Rivero et al., 2004). The latter results were confirmed by Weber et al. (2007), who also reported a relative increase in HA relative to FA with time in soils amended with urban compost. Moreover, the added compost can lead to significant changes in the composition of SOM and minimize labile C mineralization from the soil thereby enhancing the role of SOM as a sink of organic C (Mondini et al., 2007; Spaccini et al., 2009). On the bases of CO₂ respiration results which measure microbial activity, organic matter decomposition in amended soils (Bernal et al., 1998; Fernandez et al., 2007) and C sequestration potential of arable soils (Mondini et al., 2007; Sánchez-Monedero et al., 2008; Adani et al., 2007) have limitations in applying the results to field conditions and generalisation. For instance, under field conditions the decomposition and stability of organic C is a function of dynamic, heterogeneous and interactive variables such as the amount and quality of plant material entering the soil, the soil mineralogy and chemistry and other soil properties such as moisture, temperature, vegetation etc. The advantage of controlled laboratory incubation experiments is that these factors can be kept constant and restricted so that effects of one variable (e.g. compost quality) can be determined with more precision.

Coffee pulp waste may have significant adverse effects to the environment (Gezahegne et al., 2011; Negassa et al., 2011), but composted it may be a useful amendment of tropical soils. Therefore, it is important to disclose effects of coffee pulp waste composts to SOM contents, composition and stability. Relevant evidence requires the application of molecular-level sensitive analytical methods such as mass spectroscopy. For instance, pyrolysis–field ionization mass spectrometry (Py-FIMS) enabled to describe management induced changes in SOM composition in whole soil samples (Schulten and Hempfling, 1992), to characterize SOM in sewage farm soils (Leinweber et al., 1996), to trace different phases of bio-waste composting (Smidt et al., 2005) and to characterise the organic matter in fresh agro-industrial waste including coffee pulp (Negassa et al., 2011). Recently, Eshetu et al. (2012) used Py-FIMS in conjunction with pyrolysis gas chromatography/mass spectrometry to study long-term compost effects on the molecular composition of SOM developed in humus free Pleistocene loamy marl. Most recently we observed that composts taken after the thermophilic phase may have an overall better effect to soil C sequestration than mature composts (Eshetu et al., 2013). However, neither Py-FIMS nor another highly sensitive speciation method has been applied so far to disclose effects of differently aged or stabilised composts from coffee pulp waste on SOM in tropical soils.

Therefore, the objectives of the study were (1) to evaluate the effect of compost age on the molecular structure of SOM in a tropical Nitisol amended with compost derived from different phases of composting of coffee pulp waste, and (2) to investigate which constituents of organic matter were decomposed or relatively enriched, when differently stabilized composts were incubated in the Nitisol sample to simulate the microbial decomposition.

2 Materials and methods

2.1 Soil and composting samples

The soil was sampled at a coffee plantation farm located in the South-Western Highlands of Ethiopia and classified as Nitosol (ISSS-ISRIC-FAO, 1998). The sampling area is situated
temperatures range from 11 to 14 °C and 26 to 30 °C, respectively, and the mean of precipitation ranges from 1131 to 1150 mm. Thus, the climate may be indicated as warm tropical. A total of 50 subsamples were taken from 5.91 ha land, traversed in a zig-zag pattern, from soil depth of 0 to 30 cm using a GPS and an auger. The subsamples were well mixed in a plastic container and then a representative sample of 3 kg was placed in a labeled plastic bag. The soil sample was air-dried and milled to pass a 2 mm sieve. Its main characteristics are compiled in Table 1.

### Table 1


<table>
<thead>
<tr>
<th>Parameter</th>
<th>Soil</th>
<th>RCPW</th>
<th>COM1-T</th>
<th>COM1-M</th>
<th>COM1-F</th>
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<tbody>
<tr>
<td>pH</td>
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<td>5.8</td>
<td>8.8</td>
<td>9.3</td>
<td>9.1</td>
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<tr>
<td>Corg (g kg⁻¹)</td>
<td>38.6</td>
<td>397.0</td>
<td>151.0</td>
<td>149.0</td>
<td>139.2</td>
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<tr>
<td>N (g kg⁻¹)</td>
<td>3.2</td>
<td>21.1</td>
<td>10.5</td>
<td>12.7</td>
<td>12.7</td>
</tr>
<tr>
<td>S (g kg⁻¹)</td>
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<td>1.7</td>
<td>2.2</td>
<td>2.4</td>
</tr>
<tr>
<td>C/N</td>
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<td>14.4</td>
<td>11.7</td>
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<td>6.7</td>
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<td>2.1</td>
<td>2.1</td>
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<td>Soil texture</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Sand</td>
<td>84</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>% Silt</td>
<td>14</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>% Clay</td>
<td>1</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
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<tr>
<td>Phytotoxicity (Germination index in %)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With cress</td>
<td>3</td>
<td>106</td>
<td>109</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>With Radish</td>
<td>26</td>
<td>121</td>
<td>120</td>
<td>125</td>
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</tr>
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</table>

The compost was produced from 800 kg raw coffee pulp waste (RCPW) in a method of small heap composting. Heaps were piled in a bamboo box of dimensions 1.5 m (l) × 1.0 m (w) × 0.8 m (h)). The platform used has been considered as a major indicator how well the composting process was progressing. The composting was considered to be finished when the temperature of the mixture remained stable and near ambient (about 21 °C) after 16 weeks.

Representative samples (about 1 kg) were taken by mixing nine subsamples from different levels of the section in the pile at different phases of the composting, day 8 (thermophilic phase = COM-T), day 36 (mesophilic phase = COM-M) and day 119 (final compost = COM-F). In this way composts of different stability were obtained. The samples were air dried and ground to pass a 0.5 mm sieve. Main properties are shown in Table 1.

Aerobic incubation of the soil-compost-mixtures was done by mixing 10 g dry weight of sieved soil samples (< 2 mm) with fresh and composted coffee pulp waste at desired application rates (48 t ha⁻¹) and placed in 100 ml incubation vessels in five replicates each. They were monitored as treatment S+RCPW, S+COM1-T, S+COM1-M and S+COM1-F. Soil controls were run without any amendment. Distilled water (1 to 5 ml) was added to the mixtures to keep the moisture at 60 % of water-holding capacity. The incubation was carried out in a temperature-controlled incubator at 25 °C for 98 days. Subsamples (2 g) were taken destructively from each treatment at the end of incubation for elemental and Py-FIMS analyses.

### 2.2 Chemical analyses: basic data and molecular – chemical characterization

The soil samples were analyzed for pH and EC in 0.01 M CaCl₂ suspensions (1:2.5 w/v), and fresh and composed waste samples were analyzed for pH and EC in H₂O suspensions (1:10 w/v). The concentrations of total organic carbon (Corg), total nitrogen (N) and total sulfur (S) were determined for soil, compost and amended soil samples using a CNS analyzer (Vario EL III; Elementar Analysensysteme, Hanau, Germany). RCPW and compost pythotoxicity was determined according to the modified method of Zuconi et al. (1985) and described and discussed in Eshetu et al. (2013).

For Py-FIMS about 3 mg of the air dried, ground and homogenized samples were thermally degraded in the ion source (emitter: 4.7 kV, counter electrode -5.5 kV) of a double-focusing Finnigan MAT 95 mass spectrometer. All samples were heated in a vacuum of 10⁻⁴ Pa from 50 °C to 700 °C, in temperature steps of 10 °C over a time period of 18 minutes. Between magnetic scans the emitter was flash-heated to avoid residues of pyrolysis products. About 65 magnetic scans were recorded for the mass range m/z 15 to 900. Ion intensities were referred to 1 mg of a sample. For each of the
single scans, the absolute and relative ion intensities of ten classes of compounds in the organic matter were calculated by summation of the ion intensities of indicator signals to obtain thermograms of their volatilization and averaged Py-FI mass spectra. This procedure was done for each three replicate measurements per soil sample and the results were averaged for statistical analysis. Information on the molecular size distribution of pyrolysis products was obtained by calculating the molecular weight averages M_w (weight-based) and M_n (number-based), and the polydispersity (I = M_w / M_n) (Lattimer and Schulten, 1983). Detailed descriptions of the Py-FIMS methodology are published in Leinweber et al. (2009).

2.3 Statistical analyses
Means were calculated for physicochemical properties of soils, composts, amended soils and ion intensities from Py-FIMS. Comparisons between means of ion intensities of compound classes and polydispersity in different treatment were made by a One Way ANOVA test. Multivariate statistical evaluation of Py-FI mass spectra was done by principal component analysis to test which m/z signals contributed to differences among samples. All statistics were computed using data analysis and graphic software (Origin 8.1G).

3 Results and Discussion
3.1 Elemental composition
Organic amendments increased the C_{org} concentrations by 7.8 g kg\(^{-1}\) (RCPW) and about 2 g kg\(^{-1}\) (with the addition of composts) at start of the incubation (Table 2). The increases in N_t concentrations were proportionally. These differences in C_{org} and N_t concentrations originate from the different amounts of organic matter applied with RCPW and the composts (Lima et al., 2009). At the end of incubation all samples had lower C_{org} and N_t (except the S + RCPW) concentrations. The C_{org} losses were larger in the soil amended with RCPW (10.5 %) than in the samples amended with composts (2 % to 4.1 %). This difference in C_{org} losses by respiration are explained by the decomposition of easily degradable organic compounds from the RCPW which in the composts had been either mineralized (Bernal et al., 1998) or otherwise stabilized. Furthermore, the observed smallest C_{org} losses by only 2.0 % in the samples amended with compost from the thermophilic phase disagrees with the findings of (Leifeld et al., 2002; Mondini et al., 2007). These authors found an inverse relationship between the organic C mineralized and the degree of stability of the compost added in a laboratory incubation experiment and concluded that composts require a maturation phase for humification and organic matter stabilization. Explanation of this disagreement requires a detailed molecular-chemical investigation of the different composts and soil-compost-mixtures as described below.

3.2 Pyrolysis – field ionization mass spectrometry (Py-FIMS)
In the Py-FIMS the thermograms of total ion intensity (TII) shows single peaks for all the control soil and the soil amended with RCPW (Figure 1), and similar for the three samples with compost amendment (Figure 2). Addition of the organic materials slightly changed the peak temperatures of maximum volatilization of organic molecules from about 500 °C in the control to 470 to 500 °C in the samples with organic amendments (see Figure 1 and compare with Figure 2). Furthermore, the pronounced shoulder at 420 °C seen at the control soil sample (Figure 1) disappeared in the samples with organic amendments (Figure 2), indicating some stabilization of labile organic matter by the organic amendments. The signal patterns of the Py-FI mass spectra revealed differences among compost samples originating from the different duration of the composting. For instance the prominent signals at m/z 58, 72, 96, and 110 indicate a particularly high relative intensity of carbohydrates in sample S+COM1-T (Figure 2). The very intense m/z 84 in this treatment can be explained by pyrolysis products of carbohydrates and peptides. Furthermore, m/z 67 (pyrrole) and m/z 117 (indole) seem to be more abundant in this than in the other composts. Moreover, the signals with highest molecular masses originating from sterols and long-chained n-fatty acids (e.g., m/z 390, 424) were detected in this treatment only (Figure 2).

On the other hand, intense signals of phenols/lignin...
monomers (m/z 168, 180, 194), lipids (m/z 202, 216, 230), homologous series of alkanes (m/z 252, 266, 280, 294, 308) and alkylaromatics (m/z 218) were found in all spectra.

A more detailed spectra evaluation by PCA indicated that 92.4 % of the total variance in the whole data set from the three soil-compost-mixtures could be explained by the first two principal components (not shown). For 34 m/z signals the univariate Wilk’s lambda was significant at a level of p < 0.01. The signals with the highest discriminating powers among treatments S+COM1-F, S+COM1-M and S+COM1-T are m/z 114, 71, 176, 434, 399, 113, 85, 177, 189, 468, 157, 84, 219, 83, 69, 253, 228, 143, 44, 60, 221, 252, 202, 141, 72, 53, 269, 107, 82, 200, 88, 152, 233, 443 and 167 (arranged with decreasing importance for discrimination). For instance the pentose marker m/z 114 from plant material was significantly higher in treatment S+COM1-T but showed no significant difference between composts from the mesophilic and final phase. On the other side, the relative proportions of the lignin marker m/z 178 (coniferyl aldehyde) (Leinweber et al., 2009) was significantly higher in S+COM1-M and S+COM1-F than in S+COM1-T. This provides unequivocal evidence that duration of the composting has an effect on the molecular composition not only of the compost (Smidt et al., 2005) but also of a soil amended with this compost.

The data derived from the Py-Fi mass spectra pointed to similarities but also significant to differences among samples at the end of the incubation (Table 3). The proportions of volatile matter, ranging from 20 to 25 %, differed insignificantly, indicating that organic matter and adsorbed water were not greatly affected by the soil amendments. The TII values were significantly larger in all amended soils than in the control without significant differences (p < 0.05) among the amended soil samples. Assignment of markers signals to important compound classes of SOM revealed significantly larger intensities of carbohydrates, peptides and sterols in S+COM1-T than in the other treatments. Differences were largest between S+COM1-T and the control accounting for 4.4 × 10^6 counts mg^{-1} for carbohydrates, 3.9 × 10^6 counts mg^{-1} for peptides and (0.2 × 10^6 counts mg^{-1} for sterols (Table 3). The ion intensities of phenols/lignin monomers, alkylaromatics, and N-compounds were significantly lower in the control than in the amended soils but did not significantly differ among the amendments.

The relative ion intensities of compound classes indicated that carbohydrates (12.8 %) and peptides (12.2 %) were the major SOM constituents in S+COM1-T (Table 3, see values in parentheses). Furthermore, this sample contained significantly more N-compounds (7.1 %) and sterols (0.6 %) than any other sample. Phenols/lignin monomers (13.1 to 14.0 %) and alkylaromatics (14.9 to 15.4 %) were more abundant in the other amended soil samples and the control. Suberin was the compound class with smallest proportions in all samples.

The molecular weight averages M_n (142 g mol^{-1}) and M_w (194 g mol^{-1}) of S+COM1-T were significantly lower than those of the other treatments (M_n: 171 to 175 g mol^{-1}; M_w: 205 to 207 g mol^{-1}). This was due to the dominance of low molecular-weight organic compounds such as carbohydrates and N-compounds. However, a significantly higher M_n/M_w ratio (1.4) in treatment S+COM1-T indicated a higher polydispersity of the SOM in this treatment compared to the other organic amendments (1.2). This was due to the fact that the SOM in treatment S+COM1-T are complex mixtures of low molecular mass compounds (such as carbohydrates) to high molecular masses compounds (such as fatty acids and sterols) (Figure 1, Table 3).

The TII larger in the compost fertilized than in other treatments (Table 3) agreed with the C_m concentrations (Table 2). This confirms previous studies in which the TII from Py-FIMS also corresponded to the C_m concentrations of different agricultural soils (Schulten and Hempfling, 1992), organic waste materials (Franke et al., 2006) and compost-amended soils (Eshetu et al., 2012). The results provide evidence for an

<table>
<thead>
<tr>
<th>Treatment</th>
<th>VM (%)</th>
<th>TII</th>
<th>CARB</th>
<th>PHLM</th>
<th>LDIM</th>
<th>LIPID</th>
<th>ALKY</th>
<th>NCOMP</th>
<th>STER</th>
<th>PEPT</th>
<th>SUBE</th>
<th>FATTY</th>
<th>M_n</th>
<th>M_w</th>
<th>M_w/M_n</th>
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<tr>
<td>CONTROL</td>
<td>23.3a</td>
<td>30.6b</td>
<td>2.4</td>
<td>4.3</td>
<td>2.7</td>
<td>1.1</td>
<td>4.6</td>
<td>1.8</td>
<td>0.1</td>
<td>2.6</td>
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<td>0.0</td>
<td>175.7a</td>
<td>206.5a</td>
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<td>(7.7a)</td>
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<td>(8.8ab)</td>
<td>(3.4a)</td>
<td>(15.0a)</td>
<td>(5.8a)</td>
<td>(5.2a)</td>
<td>(0.2a)</td>
<td>(8.3b)</td>
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<td>(0.1a)</td>
<td></td>
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<tr>
<td>S + RCPW</td>
<td>21.1a</td>
<td>46.4a</td>
<td>3.6</td>
<td>6.1</td>
<td>3.9</td>
<td>1.5</td>
<td>7.1</td>
<td>2.6</td>
<td>0.1</td>
<td>3.4</td>
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Table 3

Results of pyrolysis-field ionization mass spectrometry: volatile matter (VM, %), total ion intensity (TII, 10^6 counts mg^{-1}), ion intensities for 10 important compound classes of organic matter (CARB: carbohydrates, PHLM: phenols/lignin monomers, LIPID: lipids, NCOMP: N-compounds, ALKY: alkylaromatics, LDIM: lignin dimers, STER: sterols, PEPT: peptides, SUBE: suberin, FATTY: n-C_{m} to n-C_{14} fatty acids in 10^6 counts mg^{-1}), relative ion intensity values in parentheses, % TII and molecular weight averages (g mol^{-1}). For explanation of treatments see Table 1. Values followed by the same letters in a column and column without letters were not significantly different at the 5 % probability level.
exogenous C input to these treatments from compost and microbial biomass (Leinweber and Reuter, 1992; Spaccini et al., 2009; Eshetu et al., 2012).

The signal patterns (Figure 2) and summed intensities of compound classes (Table 3) indicated the clearest impact of compost from the thermophilic phase on the SOM composition. The particularly high ion intensities of carbohydrates, peptides and heterocyclic N compounds are explained by their enrichment in the thermophilic phase of composting. Obviously, these compounds were not mineralized when the “thermophilic compost” is incubated with the Nitisol sample. This resistance of otherwise labile compounds (carbohydrates and peptides) can be explained by stabilization at reactive surfaces (Gregorich et al., 1996; Zech et al., 1997; Grandy and Neff, 2008; Bruun et al., 2010; Bustamante et al., 2010) of the clay-rich (84 % < 2 µm) Nitisol. The abundance of reactive clay surfaces is crucial, because both carbohydrates and N-compounds were completely decomposed in recirculated leachates from organic waste in large-scale lysimeters that offered no contact with reactive surfaces (Franke et al., 2007). Unlike the high content of n-fatty acids and sterols in the raw coffee pulp waste (Negassa et al., 2011) signals of these compounds were detected only in treatment S+COM1-T. This can be explained by the decomposition of these compounds in the later stages of composting. Smidt et al. (2005) also reported that fatty acids and sterols changed most during composting of yard and kitchen wastes studied by Py-FIMS and FT-IR spectroscopy.

The similar intensities of phenols/lignin monomers, lignin dimers, lipids and alkylaromatics among the compost-amended soils revealed that these compound classes were little affected by the degree of stabilization of composts and subsequent short-term incubation. However, their higher contents in amended soils compared to the control indicate enrichments of non-decomposable stable compounds by compost addition, irrespective of the compost maturation (Buurman et al., 2007; Stewart et al., 2011). For instance similarly large proportions of phenols/lignin monomers, lipids and alkylaromatics were also observed in both fresh and decomposed plant materials (Leinweber and Schulten, 1999), in a fresh coffee pulp waste (Negassa et al., 2011), and in long-term compost-fertilized soils (Eshetu et al., 2012). The small suberin proportions in all samples (Table 3) are explained by the origin of suberin from bark and outer covering of twigs (Hempfling et al., 1991) which were absent in these samples. The average molecular weights of the compost-amended soils agree with the results recorded for SOM accumulated after 19 and 34 years of a humus-formation experiment (Schulten et al., 1992), are greater than values observed in soils under potato cultivation and crop rotation (Schulten and Hempfling, 1992) and are below values from pig slurry fractions (Aust et al., 2009).

Figure 3 shows the temperature-resolved volatilization curves of those compound classes that were particularly enriched in the soil incubated with compost from the thermophilic phase. The maximum volatilization occurred at 390 °C (carbohydrates), 420°C (N-compounds) and 410 °C (peptides). The thermograms indicate that compounds enriched in treatment S+COM1-T were volatilized over the whole temperature range. In other words, there is no enrichment in a particularly low or high temperature range. This was also true for the comparison of the other organic amendments and the control (Figure 3).

The thermograms for N-compounds and peptides in Figure 3 show some differences to the corresponding thermograms obtained for similarly treated compost from coffee pulp waste and fruit waste (Eshetu et al., 2013). In the latter more complex compost the volatilization maxima were at 10 to 50 °C higher pyrolysis temperature, indicating that the organic parent materials affect the stability of the compost in...
Figure 2
Summed and averaged pyrolysis-field ionization mass spectra and thermograms of total ion intensity (TII, upper right inserts) of Nitisol soil samples amended with composts taken in different phases of composting (COM – compost; T – thermophilic phase; M – mesophilic phase; F – final stage)

Figure 3
Thermograms for the evolution of carbohydrates, N-compounds, and peptides derived from the pyrolysis-field ionization mass spectra
4 Conclusions

The Py-FIMS for the first time provided compelling evidence that the phase after which compost is applied to soil finally determines how stable it is in the soil. Furthermore, the results from this study suggest that it may be better to end up the composting of coffee pulp waste immediately after a short thermophilic phase and apply this “fresh” compost to soil rather than processing the compost through a mesophilic (cooling) and maturation phase of composting. Since the Nitisol used in this study was particularly rich in clay, binding of intermediate decomposition products and microbial metabolites to reactive surfaces in or clay aggregates is the best explanation for the enrichment of carbohydrates and various non-cyclic and cyclic N-containing compounds. However, our results based on small-scale laboratory incubation experiment are restricted to a single soil type and under exclusion of factors such as temperature/moisture fluctuations, meso- and macrofauna or plants and other field heterogeneity in general, so that further research in the field or using field replicates as well as investigating different soil types is recommended.

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