



## Rapid and economical quantification of black carbon in soils using a modified benzene polycarboxylic acids (BPCA) method

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### ABSTRACT

Black carbon, the ubiquitous stable product of incomplete combustion, is a potential sink for atmospheric CO<sub>2</sub> and, therefore, a contributor to the Earth's radiative heat balance. Accurate information about the distribution of black carbon in soils is important for climate change projections, given that the black carbon content of soils varies widely across the globe. In response to this issue, an accurate, rapid and cost-effective method to assess BC is needed. The use of benzene polycarboxylic acids (BPCA) as molecular markers of black carbon has the advantage of specifically tracking the polyaromatic backbone of the black carbon continuum. However, this method has three major disadvantages: (a) it is expensive; (b) it is very time-consuming; and (c) some of the literature states that care has to be taken when applying the BPCA method to organic-rich matrices. In response to these disadvantages, the aims of the present study were: (a) to check the validity of a new shorter and economical method for black carbon quantification based on BPCA as molecular markers; and (b) to study the correlation between BPCA formation during the analysis and the soil sample's OC content. The proposed method for black carbon quantification is based on the BPCA method developed by Glaser et al. (1998), but uses a simple direct elemental analysis (EA) of C content in the residue obtained after a strong digestion instead of the molecular determination by gas chromatography with flame ionisation detector (GC-FID). This simplification of the method represents a great cost reduction (in time and expense) providing a rapid and accurate method for large soil sample sets.

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### 1. Introduction

Black carbon is formed by the incomplete combustion of biomass and fossil fuels and is found nearly everywhere due to its atmospheric transport and high persistence in the environment (Jaffé et al., 2013; Bird et al., 2015). The incomplete combustion of fossil fuels and biomass leads to the formation of carbon-rich (> 60%), aromatic residues (char) and condensates (soot). Therefore, black carbon can be understood as a continuum from partly charred plant material through char and charcoal to graphite and soot particles re-condensed from the gas phase (Hedges et al., 2000; Schmidt and Noack, 2000). It is estimated that > 80% of black carbon ends up in the soil, where it can reside for hundreds to thousands of years, being relatively resistant to biological and chemical breakdown (Forbes et al., 2006; Preston and Schmidt, 2006). Black carbon is an ubiquitous type of stable organic matter

in the environment, which is a potential sink for atmospheric CO<sub>2</sub> and, therefore, a contributor to the Earth's radiative heat balance (Crutzen and Andreae, 1990; Bonan, 2008; Cheng et al., 2008). A recent escalation in interest in black carbon can be attributed to its role in global warming. Global warming is likely to increase the decomposition of soil organic carbon, and thus the release of carbon dioxide from soils, creating a positive feedback (Davidson and Janssens, 2006). Current models of global climate change that recognise this soil carbon feedback are inaccurate if a larger fraction of soil organic carbon than postulated has a very slow decomposition rate (Jenkinson et al., 1991; Zhang, 2010; Koven et al., 2011). Lehmann et al. (2008) found that by including realistic stocks of black carbon in prediction models, CO<sub>2</sub> emissions are greatly reduced. This reduction in temperature sensitivity, and thus the magnitude of the positive feedback, results from the long mean residence time of black carbon (estimated to be from 1300 to 2600 years by Lehmann et al. (2008)). Given its relevance, the consideration of the black carbon pool in soil C balance models is of great importance. However, the inclusion of the black carbon pool in climate models requires spatially explicit information regarding

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its distribution. Therefore, accurate information on the distribution of black carbon in soils is important for projections of future climate change. In response to that, an accurate, rapid and cost-effective method to assess BC in soil is required.

Several techniques have been developed for quantifying black carbon in soils and sediments as described by Roth et al. (2012). These techniques, that include optical, thermal and chemical methods, have been assessed in method intercomparison studies (e.g., Hammes et al., 2007). Most of these techniques rely on the same basic principle: black carbon is more resistant to breakdown than other forms of organic matter. However, reagent strength and the conditions of reaction vary widely. The methods also vary in their ease of use and cost. Among the different techniques, converting black carbon to benzene polycarboxylic acids (BPCA) as a proxy for pyrogenic organic carbon input and as molecular markers for combustion processes has gained increasing attention (Schneider et al., 2010). In a ring trial study, in which 17 laboratories participated and seven methods for black carbon analysis were tested on 12 reference materials, Hammes et al. (2007) pointed out that the BPCA method is the best suited for black carbon analysis in soils and sediments. The BPCA method was introduced by Glaser et al. (1998), and has since been subjected to several improvements (e.g., Brodowski et al., 2005; Schneider et al., 2011). This method has been applied in a range of studies to investigate black carbon in soil (e.g., Brodowski et al., 2007; Glaser and Knorr, 2008; Hammes et al., 2008; Llorente et al., 2010; Rodionov et al., 2010). The BPCA method converts black carbon to benzene rings, which are substituted with varying numbers (2–6) of carboxylic acid groups. This molecular marker method provides information on the nature of black carbon beyond just an estimation of the amount, as it identifies and quantifies a number of black carbon markers that can be related to source and formation conditions (Hindersmann and Achten, 2017). Because the established BPCA method is labour intensive (due to the multiple steps of the procedure), expensive (given the need for using analytical equipment such as liquid or gas chromatography, among other things) and time-consuming (sample throughput of around 20 per week), a simpler but equally accurate and precise method for soil black carbon analysis is highly desirable. In the last ten years, different faster and more reliable methods compared to gas chromatography with flame ionisation detection (GC-FID) have been published for the quantification of BPCA. For instance, Dittmar (2008) proposed an analytical technique for the routine determination of black carbon in marine dissolved organic matter using high performance liquid chromatography with diode array detection (LC-DAD) instead of GC-FID. Schneider et al. (2011) tested the same method in a suite of laboratory-produced charcoals derived from wood and grass. Recently, Hindersmann and Achten (2017) published a new method using liquid chromatography-time-of-flight-mass spectrometry with a reproducibility comparable to the LC-DAD method but higher sensitivity. These methods represent an interesting reduction of the time needed for black carbon analysis, because no derivatization step is necessary. However, a simpler method is still desirable, especially when just quantitative information is needed.

Therefore, our study attempts to test a modified BPCA method for black carbon quantification that is easier and more economical, thus enabling a much higher sample throughput. Assuming that the aromatic carbon within the sample is black carbon and additional carbon is neither added nor exchanged (Ziółkowski et al., 2011), we tested a shortened method substituting the chromatographic separation of individual BPCA for a simple direct elemental analysis (EA) of C content in the residue obtained after a strong digestion of the soil sample. The proposed method uses not only BPCAs, but all aromatic degradation products recovered after digestion with hot nitric acid at high pressure. There is, therefore,

no need for a subsequent sample clean-up, gas chromatographic separation or internal standard quantification.

On the other hand, the BPCA yield obtained by the GC-FID BPCA method, shows a significant correlation with total organic matter (OM) content of soils (Glaser and Amelung, 2003; Lehndorff et al., 2015). Kappenberg et al. (2016) hypothesized that a considerable proportion of black carbon may be produced during the sample treatment in the presence of a high amount of organic carbon. Brodowski et al. (2005), testing plant samples, found only a marginal amount of BPCA (< 1% OC), but recommended that samples expected to contain more than 100 g of OC/kg of soil, should be oxidised using a maximum of 5 mg OC. Contrary to the recommendation of Brodowski et al. (2005), Kappenberg et al. (2016) tested the potential BPCA formation at elevated OC concentration in the sample and suggested that artificial BPCA formation would remain insignificant even if the recommended threshold value for BC oxidation of 5 mg OC was exceeded. However, Kappenberg et al. (2016) use plant samples and defined structures (ellagic acid, β-carotene and chlorophyllin), but no soil samples in their study. To test this hypothesis for soil samples, we checked BPCA formation during the analysis of a collection of 36 soil samples with a gradient of organic carbon content. To ensure the collection included soil samples with exceptionally high carbon content, we performed a soil density fractionation. As was shown in Llorente et al. (2010), high values of organic carbon concentration are found in the occluded fraction (OF) and in the free fraction (FF). It has been suggested that such high concentration is due to the physical protection of OM by aggregates attributed to compartmentalization of substrate and microbial mass. Therefore, the density fractionation process has the aim of obtaining soil samples with very high organic carbon content that allows a test of the new black carbon analytical method on a wide range of organic carbon concentration. The aims of the present study were: (a) to test the proposed shorter and cheaper method for black carbon quantification; and (b) to check the relationship between the BPCA formation and the soil organic carbon content.

## 2. Material and methods

### 2.1. Set of samples: bulk soils and soil density fractions

A set of different cropped soils from different locations (French Guinea, Argentina, Brazil, Tibet and Spain) and with different amounts of organic carbon (OC) were selected. This set included bulk soil samples and soil density fractions. The locations and characteristics of the samples are given in Table 1.

Commercially available charcoal was used as reference material for the calibration of the proposed method, and maize straw (*Zea mays* L.) was used as black carbon-free material. The organic carbon concentration of the commercial charcoal was  $900 \pm 15$  g of C/kg of dry sample ( $40.4 \pm 2.4\%$  of black carbon,  $n = 6$ ), and in the maize straw it was  $440 \pm 6$  g of C/kg of dry sample ( $n = 6$ ). No black carbon could be detected in the maize straw ( $n = 6$ ).

### 2.2. Soil density fractionation

Soil density fractionation was carried out using density fractionation and ultrasonic dispersion following the method of Golchin et al. (1994) differentiating three degrees of physical protection for OM: free fraction (FF), non-protected; occluded fraction (OF), occluded within aggregates, extractable by sonication; and organo-mineral fraction (OMF), retained in the dense residue after sonication. For the fractionation, we used NaI at 1.8 g/mL as a high density solution and 300 J of sonication power, as described in Fig. 1 and also in Llorente et al. (2010). These samples were

**Table 1**

## Bulk soils and soil density fraction characteristics.

Code	Country	Soil type	Soil fraction	Depth (cm)	OC (g/kg)
1	French Guinea	Anthrosol	Bulk soil	20-30	15.2
2	French Guinea	Acrisol	Bulk soil	20-30	8.94
3	French Guinea	Plinthosol	Bulk soil	0-10	16.2
4	French Guinea	Plinthosol	Bulk soil	0-10	18.4
5	French Guinea	Acrisol	Bulk soil	0-10	13.6
6	Argentina	Anthrosol	Bulk soil	0-10	44.0
7	Brazil	Anthrosol	Bulk soil	0-15	13.3
8	Tibet	Paleosol	Bulk soil	0-40	4.63
9	Spain	Calcsol	Bulk soil	0-10	34.7
10	Spain	Calcsol	Bulk soil	20-30	31.6
11	Spain	Calcsol	OMF	0-10	19.7
12	Spain	Calcsol	OMF	0-10	13.8
13	Spain	Calcsol	OMF	0-10	22.4
14	Spain	Calcsol	OMF	0-10	44.0
15	Spain	Calcsol	OMF	0-10	14.4
16	Spain	Calcsol	OMF	0-10	23.8
17	Spain	Calcsol	OMF	0-10	25.8
18	Spain	Calcsol	OMF	0-10	21.5
19	Spain	Calcsol	OMF	0-10	24.8
20	Spain	Calcsol	FF	0-10	239.0
21	Spain	Calcsol	FF	0-10	293.2
22	Spain	Calcsol	FF	0-10	295.2
23	Spain	Calcsol	FF	0-10	227.1
24	Spain	Calcsol	FF	0-10	229.1
25	Spain	Calcsol	FF	0-10	228.8
26	Spain	Calcsol	FF	0-10	318.8
27	Spain	Calcsol	FF	0-10	296.2
28	Spain	Calcsol	FF	0-10	226.9
29	Spain	Calcsol	OF	0-10	401.1
30	Spain	Calcsol	OF	0-10	375.9
31	Spain	Calcsol	OF	0-10	364.2
32	Spain	Calcsol	OF	0-10	353.8
33	Spain	Calcsol	OF	0-10	386.2
34	Spain	Calcsol	OF	0-10	383.3
35	Spain	Calcsol	OF	0-10	368.4

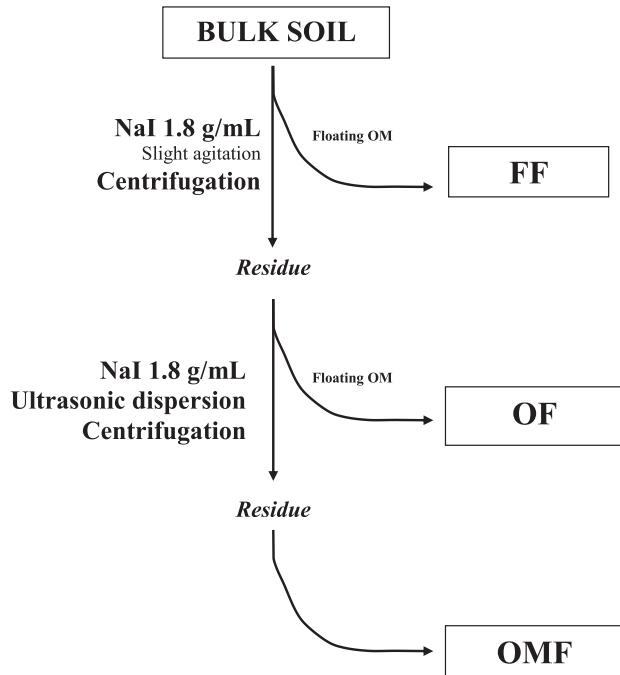
OMF: organo-mineral fraction; FF: free fraction; OF: occluded fraction.

### 2.3. Black carbon analysis

For the removal of polyvalent cations, about 0.5 g of each sample was digested with 10 mL of 4 M trifluoroacetic acid (TFA) for 4 h at 105 °C (Brodowski et al., 2005). The residue was collected by filtration through a glass fibre filter (GF 6, Schleicher and Schuell, Dassel, Germany), rinsed several times with deionized water to remove polyvalent cations/metals (such as Fe<sup>3+</sup> and Al<sup>3+</sup>, which could interfere with oxidation) and dried at 40 °C for 2 h. The dried residue was quantitatively transferred to a quartz digestion tube and oxidised with 2 mL of 65% HNO<sub>3</sub> for 8 h at 170 °C and at high pressure in a commercially available digestion apparatus (Schramel et al., 1980). After cooling, the digestion solution was filtered through an ash-less cellulose filter into a 10 mL volumetric flask, washing the residue several times with deionized water. Until this point, the GC-FID BPCA method and the new short EA of the bulk residue of oxidative degradation method that we propose are the same. A comparative schematic flow diagram of the two methods is shown in Fig. 2.

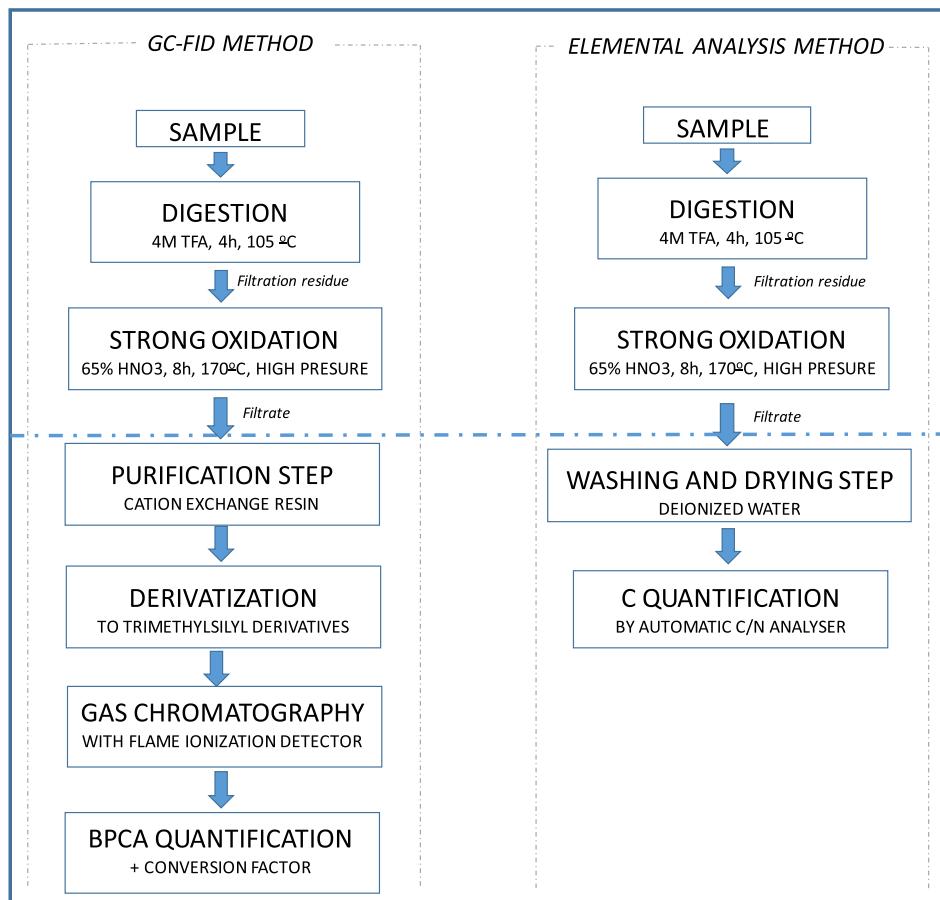
### *2.3.1. Conventional benzenopolycarboxylic acid method using gas chromatography and flame ionisation detection*

The elimination of any remaining polyvalent cations was carried out by means of cation exchange resins. A glass column (350 mm long with an inner diameter of 10 mm) was filled with strongly acidic cation exchange resin (Dowex 50 WX8, 200–400 mesh, Fluka, Germany) to a level of 60 mm. Column effluents were collected in conical flasks and then freeze-dried. An aliquot of 2 mL of digestion solution was diluted to 10 mL with deionized water to reduce the acid concentration. Then 100  $\mu$ L of citric acid (1 mg/mL)



**Fig. 1.** Procedure of the density fractionation. FF: free fraction; OF: occluded fraction; OMF: organo-mineral fraction.

included to test the proposed method in samples with a high organic carbon concentration with a large enough black carbon range for methodological evaluation.



**Fig. 2.** Comparative flow diagrams of black carbon measurement by gas chromatographic separation of individual benzenopolycarboxylic acids (left) and by bulk benzenopolycarboxylic acids quantification (right).

was added as an internal standard. Subsequently, the solution was placed on top of the prepared column. After complete elution of the sample, the resin column was washed with 50 mL of deionized water in portions of 10 mL. The combined eluates were freeze-dried. For derivatisation, the freeze-dried BPCAs were re-dissolved in methanol and transferred to 5 mL reaction vials with teflon-lined screw caps. The solvent was evaporated with a stream of ambient air. Before complete dryness, 100 µg of biphenyl-2,2'-dicarboxylic acid dissolved in methanol were added as a second internal standard. Then, the dried BPCAs were converted to trimethylsilyl ether derivatives and gas chromatography was performed with a Hewlett Packard 6890 GC, equipped with an HP-5 capillary column (30 m × 0.25 mm × 0.25 µm film thickness) and a flame ionisation detector. The BPCA yield was corrected for CO<sub>2</sub> loss and insufficient conversion of black carbon to BPCAs using the factor of 2.27 as proposed by Glaser et al. (1998) and corroborated by Brodowski et al. (2005). Although there have been other conversion factors suggested in the literature (e.g., Schneider et al., 2011) we used the conversion factor of 2.27 following a better comparability of obtained black carbon values.

### 2.3.2. Benzenopolycarboxylic acid quantification by elemental analysis: a new short method for black carbon quantification

For the proposed new method, the remaining 8 mL aliquot of the filtered digestion solution was dried in a flask using a hot plate at 60 °C, washed with deionized water and dried several times to ensure a complete removal of nitric acid and toxic nitrous oxide gases (performed in a fume hood). Subsequently, the residue was quantitatively weighed by subtracting the weight of the empty

flask from the flask with the dried BPCA residue. Finally, total C was analysed by automated C and N analysis (CHN-2000, Leco).

### 2.4. Statistical analyses

Data analysis and statistics were performed with the R 3.3.2. software (R Core Team, 2016).

## 3. Results and discussion

### 3.1. Is the proposed rapid and economical method suitable for soil BC quantification?

The set of 35 samples (bulk soils and soil density fractions) of various organic carbon contents (ranging from 4.63 to 401.1 g O C/kg soil), were subjected to a strong oxidation leading the solubilisation of charred material. After the digestion treatment we obtained a clear and yellowish solution, without any particles. Based on the results of Glaser et al. (1998), we assume that only aromatic degradation products survived digestion and no interfering organic substances complicated the subsequent analytical procedures. All the solutions were analysed for black carbon content using the conventional BPCA GC-FID method, the proposed new shorter method (EA method) and a modification of BPCA method using only benzenepentacarboxylic acid (B5CA) and mellitic acid (B6CA) as molecular markers of black carbon. The results of the analysis following the three different methods are shown in Table 2.

Applying a one-way ANOVA to compare the OC concentration of the samples we can distinguish 3 significantly ( $p < 0.001$ ) different groups of samples: bulk soil samples and OMF samples have no significant differences respect to the OC concentration ( $21.6 \pm 10.8$  g/kg). OF samples contains significantly more OC than OMF and bulk soils ( $261.6 \pm 38.1$  g/kg), but less than FF samples ( $376.1 \pm 15.7$  g/kg).

Fitting a linear model between the BC contents obtained by the GC-FID BPCA method and the ones obtained by the proposed EA method, an  $R^2$  correlation value of 0.9607 with  $p < 0.001$  was found (Fig. 3), demonstrating that our proposed shorter method is suitable for replacing the GC separation of BPCAs for its quantification. However, if the different sample types are evaluated separately fitting a linear model between the GC-FID BPCA method and the proposed EA method, we observe a different behaviour related to sample type. We found a significantly lower  $R^2$  correlation when fitting bulk soil samples ( $R^2 = 0.6466$ ,  $p < 0.001$ ) than when fitting soil density fraction samples ( $R^2 = 0.9820$ ,  $p < 0.001$ ) (Fig. 4a and b). If we focus on the OC concentration grouping of the samples to fit the linear models, we found significantly greater correlation between both methods when comparing results of samples with high concentration of OC (OF and FF fractions). Based on these results, we can suggest that the EA method works better when high OC concentration samples are analysed ( $> 2.5$  g/kg). However, if we fit density fractions separately, we found that for OMF samples both methods are uncorrelated ( $R^2 = 0.2747$ ,  $p < 0.001$ ). These results suggest that the NaI used in the soil density fractionation process

remains mostly located in the OMF because this is the last fraction separated. It was insufficiently washed and may be interfering in the BPCA analysis and/or in the EA.

As we found significant correlations between the GC-FID method and the new EA method, our assumption that the aromatic carbon within the sample is black carbon and additional carbon is neither added nor exchanged is sound. The fact that EA method results are systematically higher by about 20% than those obtained by the GC-FID method, can be explained by additional O and H introduced during BPCA formation and detection of additional BPCA not covered by GC-FID analysis such as nitrated BPCA (Glaser et al., 1998). Also, other factors could be contributing to the results.

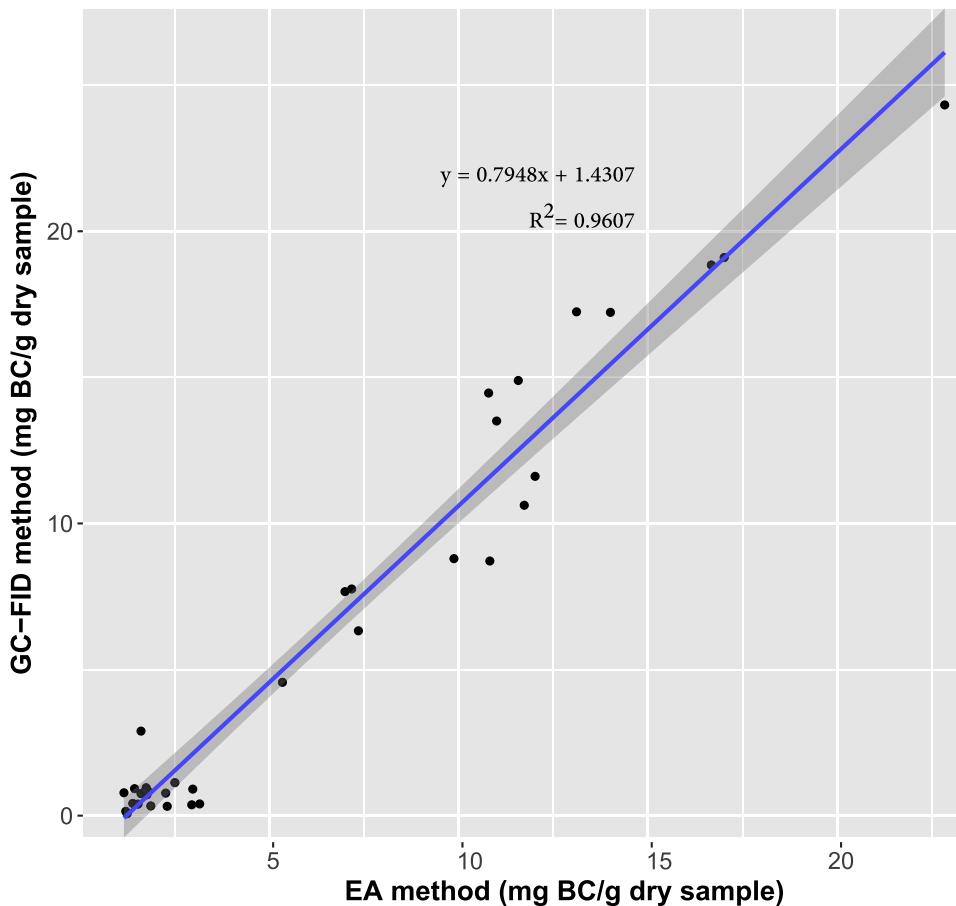
Schneider et al. (2011) identified that more sources of error and higher systematic losses in BC quantification were associated with the use of GC. This was specifically because, before analysis of the BPCAs through GC-FID, the extract needs to be cleaned in several steps and derivatised. The ring trial study of Hammes et al. (2007) to assess black carbon reported an interlaboratory reproducibility of 17%, in terms of the coefficient of variation (CV) in the replicate measurements, expressed as a proportion (%) of the mean black carbon concentration reported by individual laboratories. They highlighted certain actions that could influence in the imperfect reproducibility of the method: (a) material could be lost from the filter papers after the pretreatment wash; (b) slightly differing derivatisation conditions (duration, temperature, standing time after derivatisation); and (c) column specifications and temperature programming of the gas chromatograph. By using the EA method, at

**Table 2**

Black carbon concentrations using GC-FID BPCA method (GC-FID); BPCA method using only B5CA and B6CA as molecular markers (B5CA + B6CA) and Elemental Analysis method (EA).

	Code	GC-FID mg BC/g dry sample	B5CA + B6CA	EA
Bulk soil	1	0.72	0.36	1.77
	2	1.13	0.86	2.51
	3	0.95	0.74	1.75
	4	0.75	0.54	1.61
	5	0.92	0.76	1.44
	6	0.89	0.38	1.61
	7	0.84	0.62	1.80
	8	0.15	0.09	1.21
	9	0.83	0.20	1.87
	10	0.78	0.59	1.16
OMF	11	0.42	0.24	1.39
	12	0.37	0.23	2.95
	13	0.40	0.22	3.16
	14	0.91	0.57	2.98
	15	0.16	0.07	1.24
	16	0.40	0.15	1.53
	17	0.84	0.22	1.72
	18	0.77	0.13	2.26
	19	0.32	0.06	2.30
FF	20	7.67	4.80	7.00
	21	17.2	12.2	14.0
	22	11.6	6.77	12.0
	23	4.56	3.75	5.35
	24	7.76	4.72	7.18
	25	6.33	3.35	7.36
	26	8.72	4.73	10.8
	27	8.80	4.96	9.88
	28	10.6	6.75	11.7
OF	29	24.3	16.7	22.8
	30	13.5	9.02	11.0
	31	14.5	9.19	10.8
	32	14.9	18.8	11.6
	33	17.2	16.2	13.1
	34	18.9	10.5	16.7
	35	19.1	11.4	17.0

OMF: organo-mineral fraction; FF: free fraction; OF: occluded fraction.



**Fig. 3.** Black carbon in all samples. Correlation between conventional GC-FID method and elemental analysis (EA) method.

least (b) and (c) actions are avoided. Therefore, we suspect that the new suggested method can improve the reproducibility of the method due to the substitution of the GC step for the EA one.

Analysis of plant material (maize straw) using the EA method resulted in detection of BC in the samples ( $0.13 \pm 0.01$  mg BC/kg of sample,  $n = 6$ ). We also recommend future checking of that quantification error of the method using other black carbon-free material to check if other organic substances could interfere black carbon quantification.

### 3.2. Could B3CAs and B4CAs have been produced from organic matter during sample treatment?

Glaser et al. (1998) used the recovery of all BPCAs following strong oxidation digestion as molecular markers of black carbon in soils. BPCA yield correlated repeatedly and linearly with total organic matter content of soils and sediments (e.g., Glaser and Amelung, 2003). One explanation for co-occurrence of black carbon and soil organic matter is that the production of black carbon is highest at sites with a high amount of biomass production (Glaser and Amelung, 2003; Lehndorff et al., 2015). However, another explanation could be either the production of BPCAs from polycyclic aromatic carbon of biological origin, as unambiguously shown by Glaser and Knorr (2008). Kappenberg et al. (2016), using black carbon-free materials, showed that small amounts (< 2 g/kg OC) of B3CAs and B4CAs may be formed during sample treatment. Therefore, they suggested a production of BPCAs from biological substances and recommended that future black carbon assessment should be restricted to BPCAs with five and six carboxyl groups.

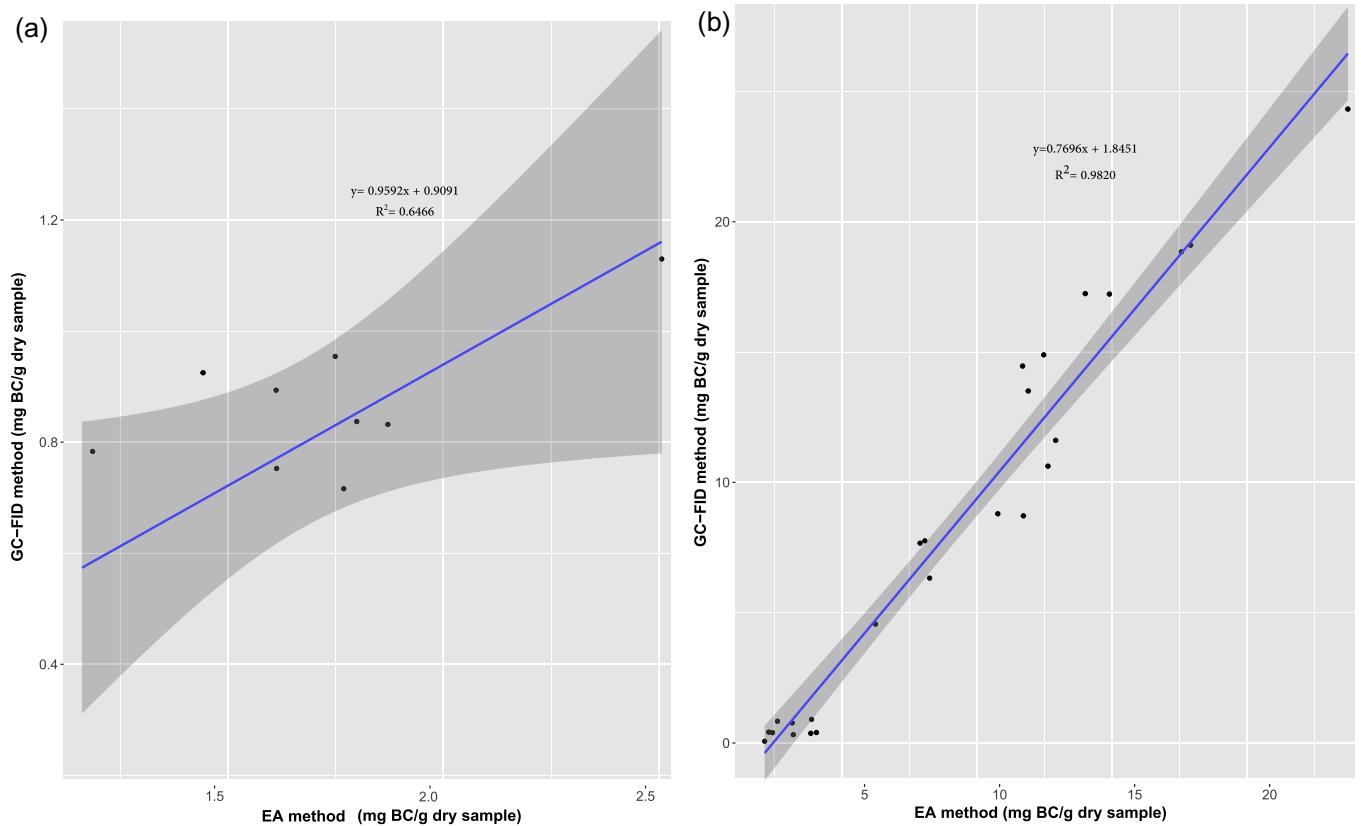
We analysed a range of soil samples (bulk soils and soil density fractions) with a wide variation of organic carbon content, estimating black carbon content using all BPCAs as molecular markers as recommended by Glaser et al. (1998), but also using only B6CAs and B5CAs, as recommended by Kappenberg et al. (2016). Results of the analysis are listed in Table 2. As shown in Fig. 5, the proportion of B3CA and B4CA formation with respect to the total BPCA formation increased only slightly as the sample's OC content increased, contrary to the observations of Kappenberg et al. (2016). In addition, a highly significant linear correlation ( $R^2 = 0.9857$ ,  $p < 0.001$ ) between the two estimations (BPCAs to B3CAs + B4CAs) was found, allowing us to conclude that the BPCA method is suitable for black carbon quantification and that B3CA and B4CA are also derived from black carbon rather than from other forms of soil organic matter.

### 3.3. Black carbon distribution among soil density fractions

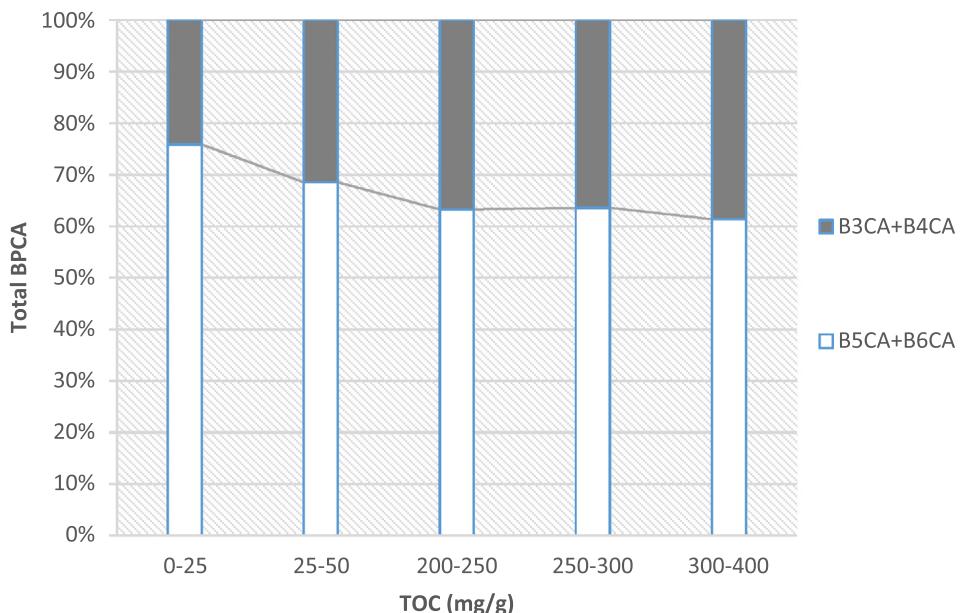
In our study, the highest black carbon concentration and the highest contribution to the overall black carbon amount in soil were found in OF, followed by FF. The black carbon contents in density fractions in this study are consistent with the findings of Glaser et al. (2000) and Rumpel et al. (2006) who reported that a major part of black carbon was not associated with the mineral phase, as well as with the findings of Skjemstad et al. (1990), who reported that black carbon may be a major component of both FF and OF.

## 4. Conclusions

We tested a simple, rapid and low-cost method for black carbon quantification using elemental analysis. This method is



**Fig. 4.** (a) Black carbon in bulk soil samples. Correlation between conventional GC-FID method and elemental analysis (EA) method. (b) Black carbon in soil density fractions. Correlation between conventional GC-FID method and elemental analysis (EA) method.



**Fig. 5.** BPCA proportion of benzenepolycarboxylic acids with three and four carboxylic groups (B3CA + B4CA) and five and six carboxylic groups (B5CA + B6CA) as function of total organic carbon (TOC).

especially versatile, when structural information about black carbon is not needed, and when high numbers of samples need to be processed. The simplification of the black carbon quantification represents a great cost reduction (in time and expense) providing a satisfactory option that allows improved knowledge regarding

this C pool. Further methodological evaluation is encouraged with respect to other types of black carbon-free organic materials such as forest litter and also other black carbon-containing matrices such as dissolved organic carbon, sediment samples and aerosol samples.

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