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What the soil organic matter term has to offer in a survey bibliographic in the last decade using science direct database

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Abstract A bibliographic survey of papers that include the term soil organic matter (SOM) and the occurrence of this term in papers in the last decade were investigated. For this purpose, it was described the composition, importance, and characterization of SOM. In sequence, the quantitative analysis to determine the scientific production, by year, including the term among 2010 and 2019 was performed by using the Science Direct database. After, the qualitative analysis of the data was included the description of the 10 main journals, and the statistics involving publications by this journal. Finally, a new bibliographic survey was realized using the advanced search and were included in the author affiliation the South America countries, and other countries. The results reinforced the importance of the SOM as soil component. In summary, the interest in research has increased in the past decade and around the globe, especially in China which published the largest number of papers among 2010 and 2019. Last year (2019) only, there were published more than 5,000 articles. Other countries, such as Ecuador, Peru, Colombia, Brazil, and India, also had a considerable increase in scientific production, during the last 10 years, involving the term SOM.

Keywords: Articles, Papers, Scientific journals, SOM

Introduction

A bibliographic survey, including the term soil organic matter (SOM), shows that in recent years this component of soil has been intensely studied worldwide. The large number of scientific papers that address this term in national and international journals is mainly due to the importance of SOM for the maintenance of chemical, physical and biological properties of soils (Dhaliwal *et al.*, 2019). Among the benefits of SOM, we highlight: decreased erosion and nutrient leaching, improvement of both water infiltration and retention in the soil, increased cation exchange capacity, the gradual nutrient liberations, increased on soil productivity, providing

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nutrients for plants, and improve the soil aggregation (Dudal and Deckers, 1993; Stevenson, 1994; Swift and Woomer, 1992; Woomer *et al.,* 1994). According to Ciais *et al.* (2013) the SOM, is a globally significant carbon reservoir, contains two to five times as much carbon than above-ground biomass, and two to four times as much carbon than is present in the atmosphere, and according to Lal (2008), its represents the main reservoir of terrestrial carbon and can be considered an important alternative to reduce atmospheric carbon emissions.

However, there is an extremely wide variety of the approach to studies involving the SOM. These make these studies contribute with a comprehensive discussion about composition, importance, structure, fractions, characterization, and others factors associated to SOM (Benbi *et al.,* 2014; Cheng *et al.,* 2013; Dhaliwal *et al.*, 2019; Feller *et al.,* 2012; Ferreira *et al.,* 2015; Guimarães *et al.,* 2013; Henry *et al.,* 2019; Jiménez-González *et al.,* 2019; Oyama *et al.*, 2016). This paper presents a brief overview, in the form of a bibliographic survey, about SOM. In the first moment, we presented a bibliographic review about the SOM. In the second moment with the aim at determining the scientific production including the term SOM in the last 10 years (2010 to 2019), we presented a bibliographical survey carried out using the Science Direct database. The Science Direct database is provided of Elsevier publishing company, has a respectable position in the academic environment, is easy access for the users, peer-reviewed and is open to academic community (Soykan & Uzunboylu, 2015).This study provides the first bibliographic survey of papers about SOM published in the last decade.

Materials and methods

The research finding provided a systematic review and bibliographic survey of the literature selected from Science Direct database. The keyword used for the selection included the soil organic matter (SOM) term. The number of papers published in the 10 last years (2010 to 2019) were searched. The research project explored the questions: (a) How many papers involve the term SOM in the Science Direct database among 2010 and 2019? (b) What the main international journals that published papers about SOM? (c) How many papers about SOM involving Brazilian researchers? (d) How many papers about SOM involving researchers from Argentina, Bolivia, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela, Australia, Canada, China, France, India, Germany, and USA. In this research were analyzed the publications of all the countries of South America, and of the 8 countries that have more publications including the term SOM. To answer these questions in the first time was realized a quantitative analysis by using Science Direct database and the SOM term. After the quantitative survey, a qualitative analysis of the data was carried out, which included the description of the 10 main journals, and the statistics involving publications by this journal.

In the second moment, a new bibliographic survey was realized using the advanced search by using the Science Direct database, in the term was includes SOM and in the author affiliation was included Brazil. This search included the description of the main journals, and the statistics involving publications by journal in the 10 last years (2010 to 2019). Finally, a new bibliographic survey was realized using the advanced search by using the Science Direct database, in the term was included SOM and in the author affiliation were included the South American countries, Argentina, Bolivia, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, and Venezuela, and in the second moment the countries, Australia, Canada, China, France, India, Germany, and USA.

Results

Statistics involving publications by year

The distribution of papers including the term SOM published by year, during 2010 and 2019, by using the Science Direct database is shown in Figure 1.

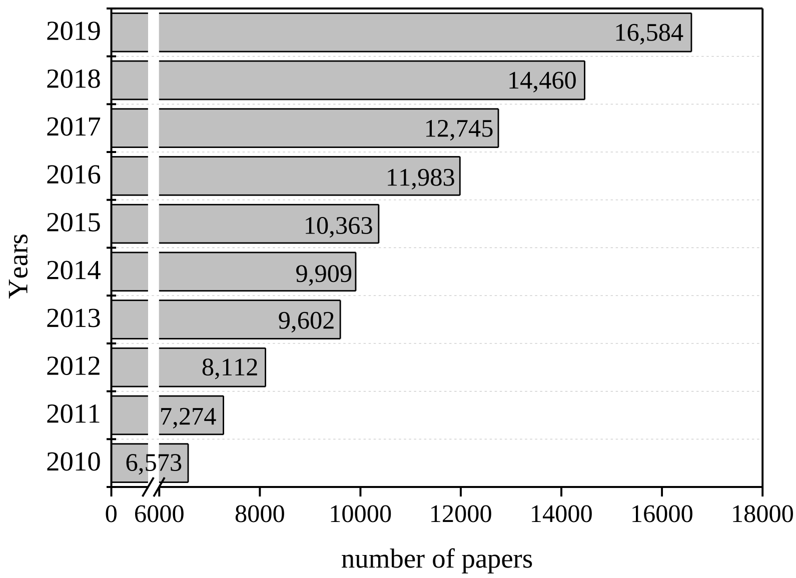

Figure 1. Distribution of papers that includes the term SOM published by year, among 2010 and 2019, by using the Science Direct database

Science Direct is a part of Elsevier. The company is the world's largest scientific, technical and medical information provider (Khiste and Awate, 2018). There are currently over 1.2 million papers on Science Direct are open access. In Science Direct database, the most widely used form to publishes including the term SOM are the research articles, book chapters, and review articles.

The results showed a literally "exponential" growth in the number of publications among 2010 and 2019. In last 2 years (2018 and 2019), the number increased around of 1,702 and 2,132 per year, respectively. In total, an increase of approximately 152% was observed among 2010 and 2019. In total, among 2010 and 2019 were published 107,593 papers involving the term SOM by using the Science Direct database. In the *Web of Science*, similar result was obtained, 110, 826 papers involving the term SOM among 2010 and 2019.

Statistics involving publications by journal

Science Direct publishes 4,220 journals and 29,895 books. Among these, 3,378 publications are from domain Life Sciences - Agricultural and Biological Sciences.

In the last 10 years, the papers including the term SOM were mainly published in the ten international journals in Science Direct database: Agriculture, Ecosystems & Environment, Bioresource Technology, Chemosphere, Environmental Pollution, Forest Ecology and Management, Geoderma, Soil and Tillage Research, Soil Biology and Biochemistry, Science of The Total Environment, and Water Research.

These journals present Qualis A1. This result indicates that the journals related to the publication of papers involving the term SOM have the highest classification according to Qualis system. The Qualis system was introduced in 1998 by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), with purpose is to evaluate and foster the Brazilian graduate programs (De Andrade and Galembeck, 2009). Actually, this system classifies publications in strata (eight levels – A1, A2, B1, B2, B3, B4, B5, and C) that are further used to evaluate a particular graduate program. This system has been changed along the years (Kellner, 2017), and is the subject of much discussion.

In 2019, CAPES presented a new proposal for the evaluation of journals. The main characteristic of which is the unique classification for all areas, based on a new methodology. According to new Qualis the 10 international journals presented in Table 1 presented the highest classification according to new Qualis system, A1.

The lists the 10 journals, in Science Direct database, that have published the greatest number of SOM papers in the past 10 years and statistics involving publications by journal per year (Table 1).

Table 1. The 10 journals that have published the greatest number of SOM papers

Journal	Number of papers									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Agriculture, Ecosystems & Environment	138	108	144	121	183	161	284	191	199	131
Bioresource Technology	185	204	180	175	166	179	259	266	331	325
Chemosphere	196	246	211	307	242	305	447	544	532	542
Environmental Pollution	174	182	146	180	147	109	289	295	375	431
Forest Ecology and Management	92	109	104	166	131	121	174	139	149	159
Geoderma	227	186	213	236	289	189	332	314	335	506
Soil and Tillage Research	79	93	96	111	88	133	155	134	170	267
Soil Biology and Biochemistry	219	244	200	312	287	268	249	228	264	230
Science of The Total Environment	193	174	323	293	567	518	874	908	1,420	1,863
Water Research	101	116	105	129	128	119	173	139	175	198

Statistics involving Brazilian researchers

The distribution of papers are published by year, during 2010 and 2019, using the term SOM and Brazil in the author affiliation, by using the Science Direct database (Figure 2).

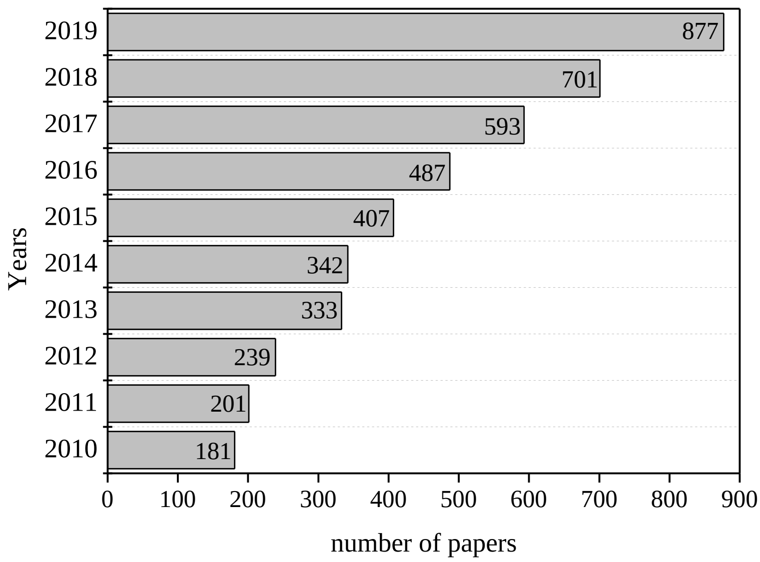

Figure 2. Distribution of papers involves Brazilian researchers about SOM published by year, among 2010 and 2019, by using the Science Direct database (advanced search)

Similar to observed in Figure 1, there was literally ‘‘exponential’’ growth in the number of publications including the term SOM in Science Direct database, among 2010 and 2019, that involves the Brazilian researchers.

In total, 4,361 papers involving Brazilian researchers were published in the last 10 years. This number correspond to approximately 4% of the papers about SOM published in Science Direct database. This result confirms that the SOM has been intensely studied by Brazilian researchers in the last 10 years.

Brazil is a large complex country that has been going to economic, social, and environmental change. The significant increase in the publications by Brazilian researchers, around 385%, can be associate the expansion of the universities, research centers, and postgraduate programs. According to CAPES the data made available on the Sucupira platform show that in 2010 and 2019 there were 2840 and 4647 postgraduate programs, respectively. In consequence, publications had increase significantly in the last decade. In addition to these, the increase in Brazilian collaboration with other countries and industries (Clarivate Analytics, 2018), the increase in Brazilian scientific journals in international databases (Strehl *et al.*, 2016) and the increase in pressure from the federal government, through CAPES, which prioritizes the number of articles published to conceptualize national programs (Volpato and Freitas, 2003), are factors associated with the significant increase in the number of publications.

This growth can also be associated with the increase in the number of journals indexed by Science Direct database, similar to that observed by other platforms, such as, Web of Science database.

Statistics involving researchers from South American countries

The total number of papers published by South American researchers in Science Direct database, involving the term SOM is shown in Figure 3.

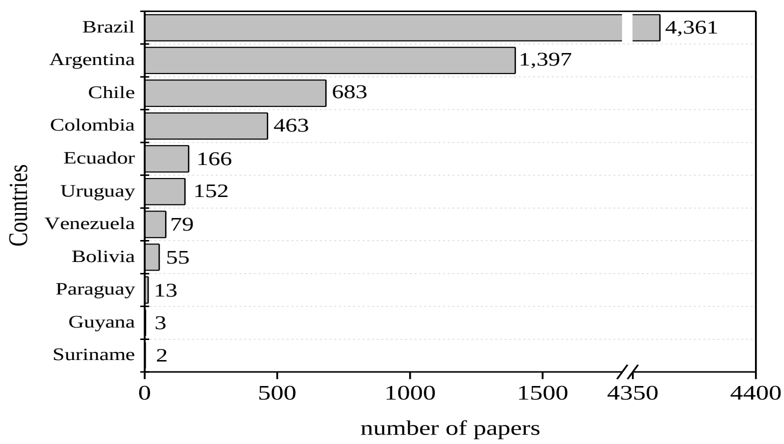

Figure 3. Total number of the papers published by South American researchers involving the term SOM in the last 10 years (2010 to 2019), by using the Science Direct database (advanced search)

The comparation among South American countries, Brazil, Argentina, Chile, Colombia, Ecuador, Uruguay, Venezuela, Bolivia, Paraguay, Guyana, and Suriname showed that the Brazilian researchers presented the largest number of published papers in Science Direct database, involving the term SOM. In total of the papers published by South American researchers, 58% were published by Brazilian researchers, in sequence Argentina, Chile and Colombia presented scientific production correspondent to 18; 9; and 6%, respectively, of total papers published in Science Direct involving the term SOM.

The number of papers published by researchers from South American countries correspond to approximately 7% of total of the papers involving the term SOM published in Science Direct database. Among the South American countries, the greater growth was observed by Ecuador, from 2 papers in 2010 to 40 papers in 2019, followed by Peru and Colombia with an increase of around 460 and 440%, respectively.

Statistics involving researchers from other countries

In the analysis of affiliation shown in Figure 4, showed that the country with greater number of papers, in the last 10 years, involving the term SOM is the China (23,484 papers), followed by Germany (7,631 papers), France (6,867 papers), Australia (5,765 papers), India (5,328 papers), Canada (5,210 papers), and USA (4,946 papers).

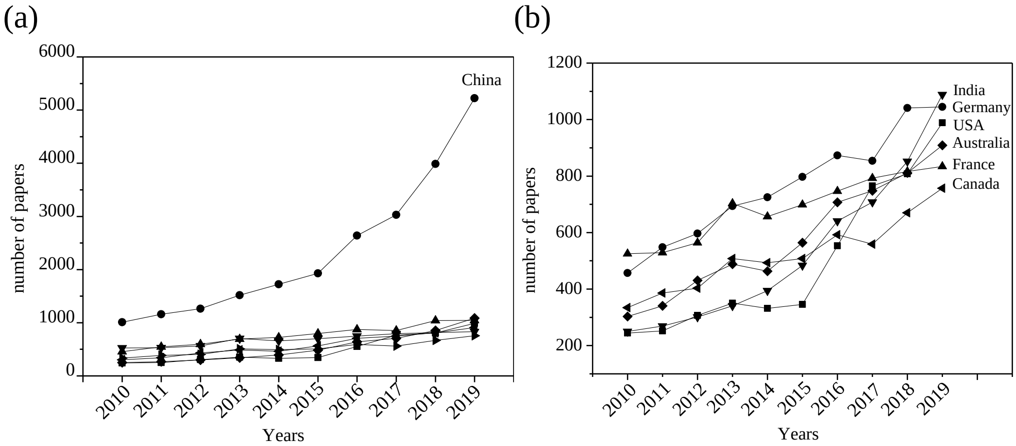

Figure 4. Growth curve of publications involving the term SOM in all word (a) China is the country that publishes the most articles related to the subject (b) Other countries with more publications

These countries have corresponded to approximately 55% of the total papers published in Science Direct database including the term SOM in the last 10 years. For all countries shown in the Figure 4, which observed an exponential growth in the number of publications including the term SOM in Science Direct database, among 2010 and 2019.

China’s output of research papers including the term SOM has significantly expanded (around 418%) from 2010 to 2019 (Figure 4a). The growth in the number of papers was followed by India (335%) and USA (305%) (Figure 4b). China is progressing with unprecedented economic growth in human history and, consequently, has been observed a great expansion in other areas such as scientific research. In 2013, China is an open country, which allows mobility of research and international co-authorship, resulting in articles with high scientific impact (Wagner and Jonkers, 2017). China’s international scientific collaboration with a handful of countries, among which the USA, Japan, Australia, Canada, Germany, can may also be one of the reasons for the large number of articles in the literature involving Chinese researchers.

In addition to other factors, it is due to the gradual investment to the Chinese government's in science and technology. According to Science and Engineering Indicators 2018 report has released by National Science Bord, the China is the country that produces the most scientific articles in the world. This report highlights that China has rapidly increased its research and development spending since 2000, an average of 18% per year. It is mainly focused on development, and not on basic or applied research. During the same period, research and development spending in the USA grew by only 4%. Other countries, such as Japan, United Kingdom, and Mexico, published 2,401; 2,235; and 1,623 papers, including the term SOM, among 2010 and 2019 in Science Direct database.

Discussion

Soil organic matter – Composition

The SOM can be defined as all organic, vegetable, or animal material including waste fragments, microbial biomass, soluble compounds, and organic matter linked to clay minerals (Stevenson, 1994). According to Manlay *et al*. (2007), the SOM is the non-living product of the decomposition of plant and animal substances. It is often considered a strong indicator of soil fertility and degradation. The SOM is extremely heterogeneous in terms of chemical structure (Christensen, 1995). According to Kögel-Knabner (2002), the composition of SOM varies widely according to the amount, composition, and properties of litter plants that provide the primary resources for organic matter formation in soil, and other factors. The plant litter materials that provide the primary resources for organic matter formation in soil are composed of complex mixtures of organic components, mainly polysaccharides, lignin, aliphatic biopolymers, and tannins (Kögel-Knabner, 2002). The composition and relative abundance of these components may vary (Kögel-Knabner, 2002). Baldock and Nelson (2000) affirmed that the SOM is a heterogeneous mixture of organic carbon species with turnover times ranging from minutes to millennia. Although, yet it remains largely unknown why some SOM persists for millennia whereas other SOM decomposes readily and this limits our ability to predict how soils will respond to climate change (Schmidt *et al.*, 2011).

Soil organic matter – Importance

The SOM is the most important component in maintaining soil quality because of its role in improving physical, chemical and biological properties (Dhaliwal *et al.,* 2019), for this reason, it has been used as an indicator of the soil quality (Duval *et al*., 2013; Franzluebbers, 2002; Imaz *et al.*, 2010). According to Manlay *et al*. (2007), the SOM is often considered a strong indicator of soil fertility and degradation. Zech *et al*. (1997) describe that the SOM is considered a great indicator of soil quality in agricultural areas, and the most important source of cation exchange capacity in tropical soils dominated by kaolinite and amorphous oxides.

SOM plays an important role in maintaining the productivity of soils, provides energy and substrates, and promotes biological diversity. Under tropical and subtropical conditions in Brazil, agricultural production and environmental quality should be based on the maintenance of both the amount and quality of the SOM (Wendling *et al*., 2010).

According to Amundson *et al.* (2015), the loss of SOM is considered a major threat to sustained soil functions.

Soil organic matter – Physical and chemical fractions

A variety of methodologies for physical and chemical fractionation have been applied in the studies that involve the SOM characterization (Christensen, 2001; Gao *et al.*, 2019; Guimarães *et al.*, 2013; Nyawade *et al*., 2019; Pinheiro *et al.*, 2015; Plante *et al*., 2006; van Wesemael *et al.,* 2019; Yeasmin *et al.*, 2020). These extraction methods have been explored because the separation of organic matter from the mineral matrix facilitates characterization by chemical and spectroscopy techniques (Wander, 2004). The studies using nuclear magnetic resonance (NMR), electron paramagnetic resonance (EPR), high-performance liquid chromatography (HPLC), gas chromatography-mass spectrometry (GC-MS), wet chemistry, and elemental analyses would be impossible to apply to intact soils (Wander, 2004). In this way, the soil preparation (extraction and/or physical and chemical fractionation) is useful to researchers actively work in studies related to organic matter stabilization.

In the literature, there are numerous methods for physical fractionation (Cambardella and Elliott, 1992; Christensen, 2001; Elliott and Cambardella, 1991; Gavinelli *et al.*, 1995; Plaza *et al.*, 2012; Sohi *et al.*, 2001) and chemical fractionation (Ping *et al.,* 2001; Swift, 1996) of SOM. In general, the physical methods can be densimetric or granulometric, or a combination between them (Elliott and Cambardella, 1991). Cambardella & Elliott (1992) described a physical method to obtain the particulate organic matter and mineral associate organic matter fractions. This methodology dispersing the soil in hexametaphosphate and isolate the fractions passing the dispersed soil samples through a 53 μm sieve. Gavinelli *et al.* (1995) proposed an approach identical to the one utilized in particle size analysis with an estimation of the recoveries from aliquots ("aliquot"; method) of the 0–2 and 0–20 μm fractions and no entire isolation ("decanting"; method) of clay and silt.

SOM fractionation into (i) free SOM between aggregates (unprotected carbon pool); (ii) SOM occluded within macroaggregates (carbon pool weakly protected by physical mechanisms); (iii) SOM occluded within microaggregates (carbon pool strongly protected by physical mechanisms); and (iv) SOM associated with the mineral fractions (chemically-protected carbon pool) was suggested by Plaza *et al.* (2012). The fractionation procedure uses a combination of density, aggregate fractionation, and sonication procedures. Briefly, free SOM is isolated by initial density separation. Stable macroaggregates are broken up into stable microaggregates and intra-macroaggregate SOM, which is then separated by density. Sohi *et al.* (2001) developed a procedure to physically fractionate by density separation the soil into: (1) free light organic matter present within and between aggregates of soil and (2) heavy organic matter that is associated with clay, silt, and sand (heavy fraction).

The fractionation method describes by Ping *et al.* (2001) adapts and combines aspects of several methodologies established in the literature into a single procedure. This method allows the SOM to be assessed as a whole or in parts and can be performed in its entirety as a sequential procedure. The resulting fractions are, as in other methodologies, operationally defined, but fractions obtained are related to commonly cited literature methods of similar technique from which the various segments are adapted. This method more clearly separates the humic substances (humic and fulvic acids and humin) which are so significant in soils but are overlooked or overestimated by other techniques.The classical method for chemical fractionation of SOM consists in to acidify the organic colloids obtained after dispersion in dilute sodium hydroxide. According to the methodology are obtained three fractions: humic acid, fulvic acid, and humin (Swift, 1996). Humic acid precipitate in acidified solution and is soluble under alkaline conditions, fulvic acid is the fraction that is soluble under both alkaline and acidic conditions remain in suspension, and humin is the insoluble fraction of humic substances (Sutton & Sposito, 2005).

Soil organic matter - Chemical and spectroscopic characterization

In general, the studies about SOM involve the chemical and spectroscopy characterization (Henry *et al.*, 2019; Oyama *et al.*, 2016), of intact soil, chemical fractions (humic acid, fulvic acid, humin), and physical fractions (particulate organic matter, mineral associate organic matter, clay, silt, sand, and others fractions). The chemical characterization is usually employed in the quantitative analysis. For carbon determination, different methodologies have been used, such as Walkley and Black (1934), Yoemans and Bremner (1988), and elemental analysis by dry combustion. The Walkley and Black method is based on the oxidation of organic matter by $K_2Cr_2O_7$ with H_2SO_4 heat of dilution. This method is widely used by soils laboratories, due to the simplicity and low cost. However, presents analytical and environmental problems, such as dichromate waste that is produced in the procedure (Carra *et al.*, 2019; Segnini *et al*., 2008).

The Yoemans and Bremner's method consisted of a simple method for routine determination of organic carbon in the soil. It involves the digestion of the soil sample with an acidified dichromate solution ($K_2Cr_2O_7$ and H_2SO_4) for 30 minutes in block digester preheated to 170 ℃, and the estimation of the unreacted dichromate by titration.

The elemental analysis (based on a dry combustion method) is considered the standard method for the determination of total soil carbon (Sato *et al*., 2014). In general, the combustion tube in the elemental analyzer at high temperature (1150 ℃) oxidizes samples in the presence of oxygen gas. The thermal conductivity detector determines the desired measuring components in succession with the help of specific adsorption columns (Dhaliwal *et al.*, 2014). However, the cost of each analysis and equipment maintenance is high (Segnini *et al.*, 2008). In addition to the quantitative methods described above, others have been used to quantify the carbon content (Baldock *et al.*, 2014; Carmo and Silva, 2012; McDowell *et al.*, 2012; Nicolodelli *et al.*, 2014). In the literature, the advantages and disadvantages of each methodology have been presented in terms of accuracy, cost, convenience, and others important factors (Fernandes *et al*., 2015; Jha *et al.*, 2014; Pereira *et al.*, 2006; Sato *et al*., 2014; Segnini *et al*., 2008).

The spectroscopic characterization is usually employed in the qualitative analysis. The Raman, Fourier transform infrared (FTIR), NMR, Ultraviolet-Visible (UV-Vis), EPR, and fluorescence spectroscopies are some of the common techniques employed. Vibrational spectroscopy techniques provide a powerful approach to the study of the soil structure (Xing *et al.*, 2016). Although FTIR spectroscopy is the most prominent type of vibrational spectroscopy used in the field of soil science (Aranda *et al.*, 2011; Barančíková *et al.,* 2018; Baumann *et al.*, 2016; Dick *et al.*, 2003; Fabris *et al.*, 2019; Santos *et a*l., 2010), applications of Raman spectroscopy in this area continue to increase. The ability of FTIR and Raman spectroscopies to provide complementary information for organic and inorganic materials makes them ideal approaches for soil science researchers (Carrero *et al.*, 2012; Leyton *et al.*, 2008; Parikh *et al*., 2014; Ribeiro-Soares *et al.*, 2013; Xing *et al.*, 2016). Ultraviolet-Visible spectroscopy is applied to estimate the humification degree of SOM by E_4/E_6 ratio (Chen *et al*., 1977). In the literature, the ratio between absorbances at 465 and 665 nm has been used in the studies about involving the SOM characterization (Carra *et al*., 2017; Nogueira *et al.*, 2018; Saab and Martin-Neto, 2007; Santos *et al*., 2010).

In recent years, NMR and EPR have help in the studies about the structure and reactivity of SOM (Abakumov *et al.*, 2015; Barančíková *et al.*, 2018; Cao *et al.*, 2011; Courtier-Murias *et al*., 2013; Segnini *et al*., 2010). The ^{13}C NMR has been extensively used to determine the amount of aromatic and aliphatic groups and thus the humification degree (Santos *et al*., 2010). The concentration of semiquinone-type free radicals (‘spin’), determined by EPR, has been associated with the humification degree of SOM (Riffaldi and Schnitzer, 1972), and have elucidated some aspects related to chemical structures, functions, and reactivity of SOM (Bayer *et al.*, 2002; Segnini *et al.,* 2010). Fluorescence spectroscopy has been applied to investigate organic matter composition and humification in recent years (Martins *et al.*, 2011; Santos *et al.*, 2010; Segnini *et al*., 2010). Based in this spectroscopy several humification indexes have been proposed (Kalbitz *et al*., 1999; Martins *et al.*, 2011; Milori *et al.*, 2002; Milori *et al.*, 2006; Zsolnay *et al*., 1999). The use of fluorescence spectroscopy in the qualitative characterization of SOM is supported by the presence of various fluorescent structures in the SOM, which includes condensed aromatic compounds with several functional groups. In general, the spectroscopic techniques such as FTIR, UV-visible, NMR, EPR, and fluorescence allows identification of functional groups and molecular structures. These techniques providing a better understanding of SOM qualitative characteristics.

The bibliographic survey including the term SOM reinforce the importance of this soil component. The bibliographic review shows the challenges in determining its composition, the important contribution of characterization studies involving physical and chemical fractions and chemical and spectroscopies techniques. In summary, and as shown by the increasing number of papers collected in journals indexed in Science Direct database, the interest in research has increased in the past decade and around the globe, especially in China that published 24,415 papers among 2010 and 2019. Other countries, such as Ecuador, Peru, Colombia, Brazil, and India, also had a considerable increase in scientific production, during last 10 years, involving the term SOM.

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