# Critical Analysis of the van Bemmelen Conversion Factor used to Convert Soil Organic Matter Data to Soil Organic Carbon Data: Comparative Analyses in a UK Loamy Sand Soil

# Análise Crítica do Fator de Conversão van Bemmelen usado para Converter Dados de Matéria Orgânica de Solo em Dados de Carbono Orgânico: Análises Comparativas em um Solo Franco-Arenoso do Reino Unido

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**Abstract:** Converting soil organic matter (SOM) data to soil organic carbon (SOC) data usually uses the van Bemmelen factor of 0.58 (or in reverse its reciprocal of 1.724) as a universal conversion factor. The accuracy of this conversion factor has been questioned. Under the Kyoto Protocol (1997) dry combustion is recommended to provide reproducible analyses to measure soil carbon stocks. However, dry combustion equipment is expensive and entails high maintenance. For rapid and inexpensive measurements, loss--on-ignition (LOI) is often used. A total of 278 loamy sand topsoil (0-5 cm depth) samples were taken during three soil sampling sessions (9 January 2007, 22 January 2009 and 10 October 2011) from runoff plots, splash erosion plots and grassed/cultivated plots on the Hilton Experimental Site, Shropshire, UK. A total of 124 soil samples were collected from both runoff and splash plots in both 2007 and 2009 (Bhattacharyya *et al.,* 2011a). Some 22 of the collected samples in 2011 were from grassland (Ah horizon) and eight from cultivated soils (Ap horizon). Homogenized soil samples were split and SOM was deter-

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mined on oven-dried samples by LOI and total SOC was determined by dry combustion. A conversion factor of 0.845 was used to obtain SOC from total soil C, following Rawlins *et al.* (2011). Results showed strong associations ($R^2$ = 0.70, P <0.001, n = 278) between SOM and SOC data. For all data, SOM to SOC conversion factors varied between 0.36-0.98, with a mean value of 0.66 (SD = 0.105). The mean values of the conversion factor were 0.64, 0.69 and 0.56, respectively, for the samples collected in 2007, 2009 and 2011. Results indicate the van Bemmelen factor (0.58) is a reasonable predictor, but both temporal and spatial variations occur around it within a specific soil type. Thus, caution should be exercised in SOM/SOC data conversions using the van Bemmelen factor.

Keywords: Soil Organic Matter; Soil Organic Carbon; Hilton Experimental Site; van Bemmelen Conversion Factor.

**Resumo:** Para conversão de dados de Matéria Orgânica de Solo (SOM) em dados de Carbono Orgânico de Solo (SOC) geralmente se usa o fator van Bemmelen de 0,58 (ou inverter a sua recíproca de 1.724) como fator de conversão universal. A precisão deste fator de conversão tem sido questionada. Pelo Protocolo de Quioto (1997) a combustão seca é recomendada para fornecer análises que buscam medir estoques de carbono do solo. No entanto, equipamentos de combustão a seco são caros e exigem elevada manutenção. Para medições rápidas e de baixo custo é frequentemente utilizado a perda de peso por ignição (LOI). Um total de 278 amostras de solo franco-areno foram coletados entre 0-5 cm de profundidade em sessões de três solos em 09 de janeiro de 2007, 22 de janeiro de 2009 e 10 de outubro de 2011, a partir de parcelas de erosão em áreas gramadas de pastagens e parcelas em áreas cultivadas na estação experimental de Hilton, Shropshire, Reino Unido. Um total de 124 amostras de solo foram coletadas de parcelas de escoamento superficial e de *splash* nos anos de 2007 e 2009 (Bhattacharyya et al., 2011a). Cerca de 22 das amostras foram coletadas em 2011 nas áreas de pastagens (Horizonte Ah) e oito em solos cultivados (Horizonte Ap). As amostras de solo foram homogeneizadas e divididas para análise de SOM, que foi determinada em amostras secas ao forno, e análise de LOI e SOC total que foram determinadas por via seca. Um fator de conversão de 0,845 foi utilizada para se obter o SOC total de C, seguindo Rawlins et al. (2011). Os resultados mostraram fortes associações ($R^2$ = 0,70, p <0,001, n = 278) entre os dados da MOS e SOC. Para todos os dados, a SOM e os fatores de conversão SOC variaram entre 0,36-0,98, com um valor médio de 0,66 (DP = 0,105). Os valores médios do fator de conversão foram 0,64, 0,69 e 0,56, respectivamente, para as amostras coletadas em 2007, 2009 e 2011. Os resultados indicam que o fator de van Bemmelen (0,58) é um preditor razoável, mas ambas as variações temporais e espaciais ocorrem em torno de um tipo de solo específico. Assim, deve-se ter cuidado em conversões de dados SOM/SOC usando o fator van Bemmelen.

Palavras-chave: Matéria Orgânica de Solo; Carbono Orgânico de Solo; Estação Experimental de Hilton; Fator de Conversão van Bemmelen.

## Introduction

Soil organic matter (SOM) is a fundamental soil property which interacts with multiple aspects of soil system dynamics. SOM affects soil structure, soil erodibility, moisture retention, nutrient retention and availability and the nature and properties of soil flora and fauna (LOVELAND and WEBB, 2003; FULLEN and CATT, 2004). Thus, accurate and reproducible analyses of SOM are crucial in Soil Science. Much SOM consists of soil organic carbon (SOC) and the importance of SOC is given increasing prominence due to its pivotal role in carbon storage and sequestration (BHATTACHARYYA et al., 2012) and its inter-relationships with climate change (LAL, 2008).

Progress in international comparability of SOM/SOC datasets is impeded by different countries using different analytical protocols (JANKAUSKAS et al., 2006). It is also essential to calibrate SOM and SOC values. Generally, the van Bemmelen constant is used, assuming that 58% of SOM is SOC. The constant is frequently used uncritically in Soil Science and some researchers have suggested caution in using the constant (HOWARD and HOWARD, 1990; SCHUMACHER, 2002). This study analysed the SOM and SOC content of loamy sand topsoils sampled in the UK and performed split analyses of SOC and SOM following the dry combustion method (NELSON and SOMMERS, 1982) and loss-on-ignition (LOI) (BALL, 1964), respectively, to critically evaluate the applicability of the van Bemmelen constant.

## Materials and Methods

The Hilton Experimental Site, Shropshire, UK (National Grid Reference SO778952) was established in 1979 for studies on soil erosion and conservation (FULLEN, 1998) (Plates 1 and 2). Soil texture is loamy sand, with a typical texture of 79.8% sand (2000-63 μm), 14.8% silt (63-2 μm) and 5.4% clay (<2 μm) (FULLEN and BRANDSMA, 1995; FULLEN et al., 1998). Data on the spatial and temporal dynamics of SOM have been collected since 1985. For ease, rapidity and comparability of analysis, SOM has been determined using the LOI protocol of Ball (1964) in the UK. This involves prolonged moderate temperature ignition (375$^{o}$C for 16 hours) of oven-dried fine-earth (<2.0 mm) fractions in a muffle furnace. A total of 124, 124 and 30 topsoil samples (0-5 cm) were collected on 9 January 2007, 22 January 2009 and 10 October 2011, respectively, from runoff plots and splash erosion plots, and grassed/cultivated plots in the Hilton Experimental Site, Shropshire, UK (FULLEN and BOOTH, 2006).

Different erosion control treatments were imposed in the runoff plots in 2007 and the samples were collected before and after two years of experiments. Before experiments commenced, some plots (six out of 10 plots) were under continuous pasture for over two years and were used for another study to test the effectiveness of Borassus (a palm-mat) buffer strip plots in reducing soil erosion during 2002-2004 (BHATTACHARYYA et al., 2009). Previously these plots were occasionally used for undergraduate student projects since 1998, when two (out of 10 plots) were used as bare plots. Some plots (four out of 10 plots) were permanent grassland plots. To produce a broad intra-site variation in SOM/SOC values, 22 of the collected samples in 2011 were from grassland (Ah horizon) and eight from cultivated soils (Ap horizon).

Soil samples were air-dried for seven days and then oven-dried at 105$^{o}$C overnight. Studies of the van Bemmelen conversion factor were carried out using a split-laboratory analysis of homogenized soil subsamples. SOM concentrations were analysed at the Uni-


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Plate 1 – Aerial view of the Hilton Experimental Site, Shropshire, England, UK.

Plate 2 – Detailed view of the Hilton runoff plots.

versity of Wolverhampton, UK. SOC concentrations were analysed at the Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora, India (during 2007 and 2009) and at the Indian Agricultural Research Institute (IARI), New Delhi, India, in 2011. The Wolverhampton laboratory used the LOI method of Ball (1964) on oven-dried samples (fine-earth fractions <2.0 mm).

SOM (LOI) was calculated using the equation:

[Weight soil before ignition (g) – weight soil after ignition (g)/ weight of soil before ignition (g)] x 100.

The SOC concentration of replicate <0.2 mm 5 g subsamples were analysed by dry combustion at the VPKAS, Almora, and at the IARI laboratory in New Delhi. This technique mirrored the LOI technique preparation, as it used homogenised air and oven-dried soil samples. The dry combustion technique was to place the sample into a furnace that used pure $O_2$ to combust the organic matter for 1 hour at 900ºC and then transport the gases through scrubbers to a spectrophotometric detection unit, which measured $CO_2$ evolved from the original combustion using an infrared spectrometer at infrared wavelengths of 2.6-4.0 µm. Measurements are then converted to percentages to give precise readings of organic matter content. The carrier gas used in this instance was He to transport evolved $CO_2$ to the spectrometer. We did not determine the inorganic C concentrations in the soil samples, and hence, a conversion factor of 0.845 was used to obtain SOC from total soil C for the UK topsoils, as recommended by Rawlins et al. (2011).

## Results and Discussion

Soil organic matter and SOC values along with their descriptive statistics are presented in Table 1. Conversion factors were calculated to convert the SOM values to SOC values for the sampling in individual years and for all three years. Results indicate there are strong positive associations between the SOM and SOC datasets obtained from the collected samples in 2007, 2009 and 2011 (Figures 1, 2 and 3). When all data are combined, the overall relationship is SOM = 1.42*SOC + 3.09; $R^2$ = 0.70; n = 278; P <0.001 and the conversion factor (to obtain SOC from SOM data) is 0.66 (means 66% of SOM = SOC) (Figure 4). The correlation coefficient (of SOM and SOC) was highest for the 2011 dataset (Figure 3; $R^2$ = 0.82; n = 30; P <0.001) and least for the 2007 dataset (Figure 1; $R^2$ = 0.56; n = 124; P <0.001). Although the samples were taken from the same site in 2007 and 2009, both the association between SOM and SOC and the conversion factor vary. The conversion factor (to obtain SOC from SOM data) was greatest (0.69) for samples collected in 2009 and least (0.56) for samples collected in 2011 (Table 1). Thus, the obtained conversion factor had both spatial and temporal variations, and probably depends upon management and land use practises even within a specific agro-ecosystem.

Table 1 – Soil organic matter (SOM) and soil organic carbon (SOC) concentrations of topsoil (0-5 cm) samples from the Hilton Experimental Site (UK) and the conversion factors to obtain SOC from SOM data.

| YEAR OF SAMPLING | SOIL ORGANIC MATTER (G KG$^{-1}$) | | | | | SOIL ORGANIC C (G KG$^{-1}$) | | | | | Conversion factor (SOC/SOM) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Mean | SD | N of samples | Max. | Min. | Mean | SD | N of samples | |
| 2007 | 54.6 | 23.0 | 34.8 | 7.0 | 124 | 35.5 | 12.4 | 22.2 | 5.6 | 124 | 0.64 |
| 2009 | 53.3 | 18.0 | 32.8 | 7.9 | 124 | 35.8 | 12.7 | 22.5 | 5.7 | 124 | 0.69 |
| 2011 | 82.2 | 32.5 | 56.9 | 15.7 | 30 | 47.9 | 19.9 | 31.5 | 8.6 | 30 | 0.56 |
| All years | 82.2 | 18.0 | 38.6 | 14.9 | 278 | 47.9 | 12.4 | 24.7 | 7.6 | 278 | 0.66 |

SD = Standard deviation.

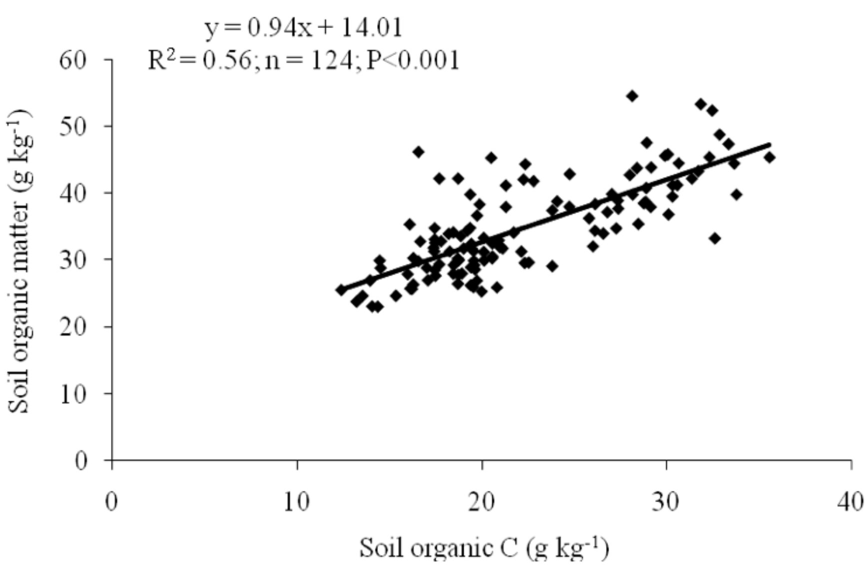


Figure 1 – Relationship between soil organic matter and soil organic carbon concentrations of topsoil samples collected in 2007 from runoff plots at the Hilton Experimental Site, UK.


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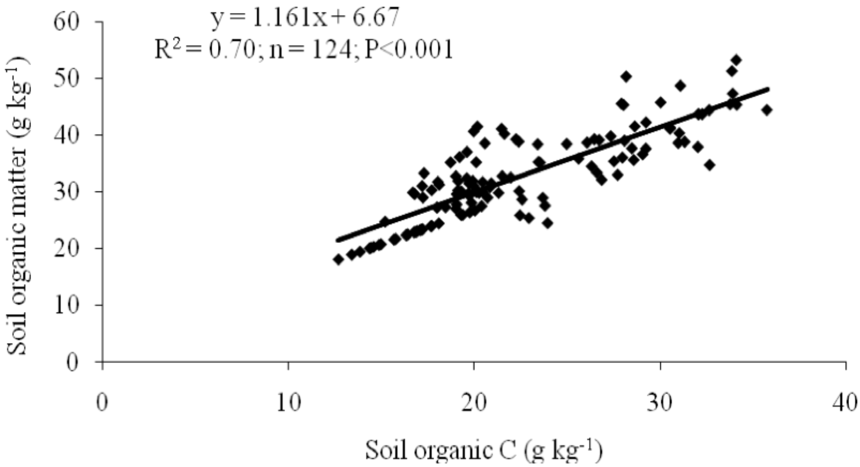


Figure 2 – Relationship between soil organic matter and soil organic carbon concentrations of topsoil samples collected in 2009 from runoff plots at the Hilton Experimental Site, UK.

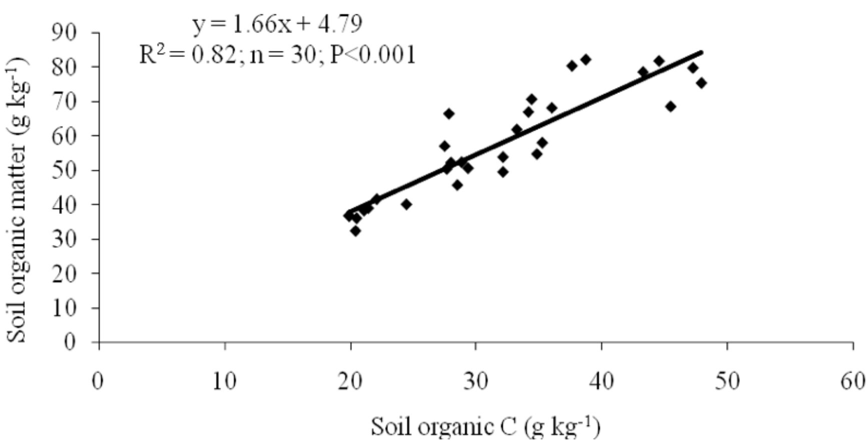


Figure 3 – Relationship between soil organic matter and soil organic carbon concentrations of topsoil samples collected in 2011 from grassed/cultivated plots at the Hilton Experimental Site, UK.


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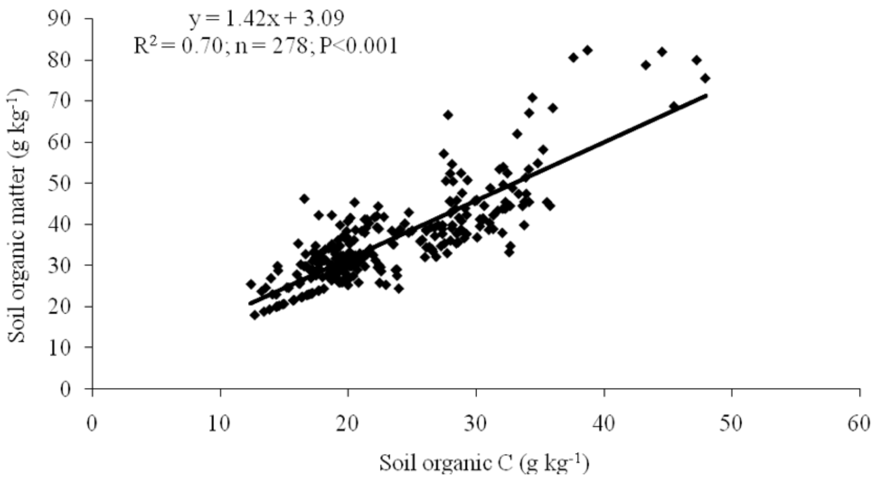


Figure 4 – Relationship between soil organic matter and soil organic carbon concentrations of topsoil samples collected in all years from runoff plots and grassed/cultivated plots at the Hilton Experimental Site, UK.

The variations in the obtained conversion factors from soil samples taken from the runoff plots in 2007 and 2009 was probably due to greater decomposition of topsoil SOM and partly due to soil conservation by the Borassus and Buriti mats (BHATTACHARYYA et al., 2011a). The initial (2007) SOM of Hilton comprised of additional products, including partially-decomposed or undecomposed organic materials; whereas the 2009 soil samples were more decomposed and contained less partially-decomposed or un-decomposed organic materials (BHATTACHARYYA et al., 2011b). The 2007 soil samples might have contained more non-humified compounds (mainly plant tissues) to yield less total soil C of SOM compared with the 2009 soils (STEVENSON, 1994). Topsoil conservation might also assist decomposition processes.

Gaining SOC data through LOI using the van Bemmelen conversion factor 1.72 (SOC = 0.58% of SOM) is useful for general analysis of soil when precise data are not required, due to its relatively low expense. However, results from data gained using this conversion factor should not be used in precise measurements for calculating carbon stocks. The intra-site matrix gathered from the sample collection points indicate that there are spatial and temporal fluctuations in SOM, which strengths the assertion that the van Bemmelen conversion factor provides an initial approximation and should be used cautiously in conversions between SOM and SOC data.

## Conclusions

Multiple analyses (n = 278 topsoil samples) suggests a mean conversion factor to obtain SOC in the 0-5 cm soil layer from SOM for the Hilton Experimental Site, Shropshire (UK), is 0.66 (or 66%). This highlights that assessing SOC from LOI serves as a useful


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initial approximation, but is not a totally accurate technique. In the case of the Hilton Experimental Site, the van Bemmelen conversion factor (0.58) usually underestimated the topsoil SOC content. The mean values of the conversion factor were 0.64 (n = 124 samples), 0.69 (n = 124 samples) and 0.56 (30 samples) for samples collected in 2007, 2009 and 2011, respectively. Results showed strong associations ($R^2 = 0.70$, $P < 0.001$, n = 278) between SOM and SOC data. However, obtaining an accurate conversion factor also requires estimation of soil inorganic C content.

## References

BALL, D. F. Loss-On-Ignition as an Estimate of Organic Matter and Organic Carbon in Non-Calcareous Soils. *Journal of Soil Science*, n. 15, p. 84-92, 1964.

BHATTACHARYYA, R.; FULLEN, M. A.; DAVIES, K.; BOOTH, C. A. Utilizing Palm Leaf Geotextile Mats to Conserve Loamy Sand Soil in the United Kingdom. *Agriculture, Ecosystem & Environment*, n. 130, p. 50-58. 2009.

_____; _____; BOOTH, C. A. Using Palm-Mat Geotextiles on an Arable Soil for Water Erosion Control in the UK. *Earth Surface Processes and Landforms*, n. 36, p. 933-945, 2011a.

_____; _____; SMETS, T.; POESEN, J.; BLACK, A. Using Palm Mat Geotextiles for Soil Conservation. I. Effects ON Soil Properties. *Catena*, n. 84, p. 99-107, 2011b.

_____; TUTI, M. D.; KUNDU, S.; BISHT, J. K.; BHATT, J. C. Conservation Tillage Impacts on Soil Aggregation and Carbon Pools in a Sandy Clay Loam Soil of the Indian Himalayas. *Soil Science Society of America Journal*, n. 76, p. 617-627, 2012.

FULLEN, M. A. Effects of Grass Ley Set-Aside on Runoff, Erosion and Organic Matter Levels in Sandy Soils in East Shropshire, U.K. *Soil & Tillage Research*, n. 46, p. 41-49, 1998.

_____; BRANDSMA, R. T. Property Changes by Erosion of Loamy Sand Soils in East Shropshire, U.K. *Soil Technology*, n. 8, p. 1-15, 1995.

_____; WU, BO ZHI; BRANDSMA, R. T. A Comparison of the Texture of Grassland and Eroded Sandy Soils from Shropshire, U.K. *Soil & Tillage Research*, n. 46, p. 301-305, 1998.

_____; CATT, J. A. Soil Management: Problems and Solutions. Londres: Arnold Publishers, 2004. 269p.

_____; BOOTH, C. A. Grass Ley Set-Aside and Soil Organic Matter Dynamics on Sandy Soils in Shropshire, U.K. *Earth Surface Processes and Landforms*, n. 31, p. 570-578, 2006.

HOWARD, P. J. A.; HOWARD, D. M. Use of Organic Carbon and Loss-On-Ignition to Estimate Soil Organic Matter in Different Soil Types and Horizons. *Biology and Fertility of Soils*, n. 9, p. 306-310, 1990.

JANKAUSKAS, B.; SLEPETIENE, A.; JANKAUSKIENE, G.; FULLEN, M. A.; BOOTH, C. A. A Comparative Study of Analytical Methodologies to Determine the Soil Organic Matter Content of Lithuanian Eutric Albeluvisols. *Geoderma*, n. 136, p. 763-773, 2006.

LAL, R. Sequestration of Atmospheric $CO_2$ in Global Carbon Pools. *Energy and Environmental Science*, n. 1, p. 86-100. 2008.

LOVELAND, P.; WEBB, J. Is There a Critical Level of Organic Matter in the Agricultural Soils of Temperate Regions: a Review. *Soil & Tillage Research*, n. 70, p. 1-18, 2003.

NELSON, D. W.; SOMMERS. L. E. Total Carbon, Organic Carbon, AND Organic Matter. In: PAGE, A. L. *et al*. (Ed.). Methods of Soil Analysis. Part 2. *Agron. Monogr*., n. 9. ASA and SSSA, Madison, WI. p. 539-594, 1982.

RAWLINS, B. G.; HENRYS, P.; BREWARD, N.; ROBINSON, D. A.; KEITH, A. M.; GARCIA-BAJO, M. The Importance of Inorganic Carbon in Soil Carbon Databases and Stock Estimates: a Case Study from England. *Soil Use and Management*, n. 27, p. 312-320, 2011.

SCHUMACHER, B. A.  Methods for determination of Total Organic Carbon (TOC) in soils and sediments. Las Vegas: Ecological Risk Assessment Support Center, US. Environmental Protection Agency, 2002.

STEVENSON, F. J. Characterization of Soil Organic Matter By NMR Spectroscopy and Analytical Pyrolysis. In: STEVENSON, F. J. (Ed.). Humus Chemistry — Genesis, Composition And Reactions. Nova York: John Wiley, 1994, p. 265-284.

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