Ecological Indicators 49 (2014) 104–109

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Assessment of the C/N ratio as an indicator of the decomposability of organic matter in forest soils

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ARTICLE INFO

Article history:
Received 21 November 2013
Received in revised form 23 September 2014
Accepted 30 September 2014

Keywords:
Soil organic carbon
Total nitrogen
C/N ratio
Soil organic matter mineralization

ABSTRACT

The usefulness of the C/N ratio as an indicator of the decomposability of organic matter in forest soil was assessed. The assessment was based on the relationship between the C/N ratio and the contents of soil organic carbon (SOC), soil nitrogen (total N), dissolved total organic carbon (DTOC) and dissolved inorganic nitrogen (DIN). SOC, total N, DTOC and DIN were determined in soils sampled in coniferous and coniferous–deciduous forest sites from genetic horizons of 48 soil profiles. The variability of the above soil parameters was determined and the correlation between these parameters and the C/N values were calculated. It was found that the C/N ratio in soil was shaped by the difference in the mobility of both elements, whereas the decrease in the C content in subsequent horizons was mostly higher than the decrease in the N content, which means that the C/N value decreased with the depth of a soil profile. When the loss of SOC and total N contents occurs at a similar rate, the C/N ratio is maintained at a more or less stable level despite the advancing SOM mineralization. When the rate of the carbon release from SOM differs from that of nitrogen or when there is an N input from external sources, the C/N ratio does not adequately describe the process of SOM mineralization as well. The correlation coefficients between the C/N ratio and other parameters indicate that the relationships between them are not significant or that there is no correlation at all. It was found that the percentage of DTOC in SOC seemed to be a better indicator of SOM mineralization than the C/N ratio.

1. Introduction

Indicators, their development and applications are dealt with in a great part of the contemporary literature. On the basis of a review of papers published in the Ecological Indicators journal, more than 500 indicators were identified (Jørgensen et al., 2013). Although a large number of indicators correspond to the differentiation in environmental conditions, the use of acquired information for the purpose of a comprehensive assessment of the environment quality seems to be a complicated issue and, according to the authors, it is necessary to develop integrated indicators. At the same time, the authors emphasize the lack of reliable methods for aggregation of indicators and their quantification, which may result in the loss of information (Jørgensen et al., 2013). For example, the use of an indicator which consists of two variables can give false information when the individual components change in different ways, as is the case with the C/N ratio.

The C/N ratio was treated mainly as an indicator of qualitative changes in soil organic matter rather than as a quantitative measure of SOM mineralization. The authors, who evaluate the C/N ratio, associate it with soil properties and processes which can be measured (Bown et al., 2011; Ernfors et al., 2007; Nave et al., 2009; Schipper and Sparling, 2011; Springob and Kirchmann, 2003). Ernfors et al. (2007) established, on the basis of an analysis of the C/N value and N_2O emissions from dry organic forest soil, that as much as 88% of the N_2O global emissions came from soils with the C/N ratio <13. Springob and Kirchmann (2003) found that the C/N value >20 in soils could limit SOM mineralization.

Pińeiro et al. (2006) emphasized that SOM was not a homogeneous matter and contained several fractions with different susceptibility to mineralization, which means that the C/N ratio was not a measure of SOM mineralization. The authors distinguished three SOM fractions with respect to the mineralization rate: active, slow and passive, with different C/N ratios, and they thought that the shares of particular fractions might be an indicator of SOM mineralization in short time periods.

Kirkby et al. (2011) found that, after the removal of undecomposed parts from organic matter, SOM might be treated as a humus, which was characterized by nearly stable C/N, C/S and C/P ratios.

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http://dx.doi.org/10.1016/j.ecolind.2014.09.044
1470-160X/

Calculations made on the basis of Kirkby et al. (2011) data indicated that the mean C/N ratio for humus was 12.7, the mean C/N ratio in the arable soils examined by the authors was 13.6, and the mean C/N ratio for an international soil amounted to 11.6. According to Sakin et al. (2010), the C/N ratio in arable soils, which was much lower than 10, might indicate a too high N input, mainly from fertilizers.

Nave et al. (2009) suggested that the N inputs increased the primary production and soil C storage, which was accompanied by an increase in the mineral N content and a decrease in the C/N ratio. The authors considered that the mineral N input might exceed its binding capacity in biological biomass, including the microbiological biomass in SOM, especially with carbon deficiency, which caused nitrogen leaching to the ground and surface water. According to Kirkby et al. (2013), appropriate eco-stoichiometrical proportions C/N, C/P and C/S, demanded for the optimum nutrient supply of microorganisms, regulated the synthesis of microbial biomass, the share of which in SOM determined the C/N stability.

Tipping et al. (2012) estimated that between 1800 and 2000 the C/N value remained at a level of about 20 in the upper horizon of pine stand soils. According to the authors, the increase in the N deposit observed since 1800 was balanced by an increase in the C content in soils, which in turn was a cause of the C/N ratio stability.

According to Yang et al. (2012), the carbon and nitrogen contents in soil were related to soil texture and depended on the SOM stability in soil fractions. Homann et al. (2007) found a negative correlation between loam and silt fractions in forest soils and the C/N ratio. According to Santruckova et al. (2010), the C/N ratio in silt and clay forest soils of Central Russia was correlated with bulk density, moisture, pH and carbon content. Callesen et al. (2007) concluded that the C/N ratio indicated the relationship between the soil nitrogen content, soil texture and climatic conditions. Watt and Palmer (2012) suggested that the C/N was a useful indicator of site fertility and primary productivity. Variations in the C/N ratio could be attributed to the climate, soil quality and vegetation cover.

Kunlanit and Vityakon (2012) considered that SOM solubility, dissolved organic carbon (DOC) production and mobility, especially in sandy soils, depended on the chemical composition of fluxes of organic materials to the soil and the C/N ratio in these materials. Similarly, Silveira et al. (2011) found that the quantities of the produced DOC and dissolved organic nitrogen (DON) and the amounts of emitted CO_2, depended on the litter type. According to Haney et al. (2012), the amount of CO_2 emitted from soils was significantly correlated with the contents of C, N, DOC and DON, whereas no significant correlation was observed between the emitted CO_2 and C/N values in soil or between C/N and DOC. According to Santruckova et al. (2010), the soil CO_2-efflux depended on both the soil quality, including the soil bulk density, soil organic C pool, microbial transformation processes and the vegetation cover; and, thereby, on the C/N ratio.

To sum up, it may be noted that the C/N ratio is perceived as an indicator having a broad field of application, e.g., for characterization of soil properties and processes. The results obtained to date are ambiguous. Despite attempts made to establish statistically valid relationships between the C/N ratio and other characteristics of soils, sites and climatic factors, no such relationships have been detected. It may be suggested that the trends in the above relationships found by the authors result from the many-sided role of the carbon and nitrogen cycling. However, the SOM mineralization regulates both the soil quality and soil carbon stock, as well as CO_2 emissions, which is especially important in view of climate change. The problem of measuring the SOM decomposition rate is still open.

The aim of our study was to evaluate the C/N ratio as an indicator of SOM decomposition depending on the contents of SOC, total N, dissolved C and dissolved N and their fluxes in forest soil. At the same time, we assumed that the loss of carbon and nitrogen contents in subsequent soil horizons was a basic measure of SOM decomposition.

2. Materials and methods

The results on carbon and nitrogen contents in forest soils obtained in investigations conducted in various regions of Poland were used in the study (Ostrowska et al., 2006, 2010; Porębska and Ostrowska, 2013). Study plots were located in coniferous forests (CF sites) and in mixed deciduous–coniferous forests (DCF sites). Soils were sampled from particular genetic horizons to the depth of the parent material.

The CF site was represented by six study plots, in which 26 soil profiles were investigated: Borecka forest (three profiles), Goleniowska forest (three profiles), Rajgród (five profiles), Lubsko (six profiles), Tuchola (three profiles) and Janów Lubelski (six profiles). The DCF site was represented by four study plots, in which 22 soil profiles were investigated: Borecka forest (eight profiles), Goleniowska forest (five profiles), Rajgród (seven profiles) and Miłomłyn (two profiles). In total, 261 soil samples were analyzed.

The soil under each of the stands was described according to the World Reference Base for Soil Resources (WRB, 2006). In the CF site, the following soil types were identified and analyzed: Haplic Podzol (with O–AE–Es–Bhs–BC–C horizons), Albic Arenosol (O–AE–Bv–BvC–C) and Haplic Arenosol (O–A–Bhw–Bw–BwC–C), and in the DCF site – Eutric Cambisol (O–A–Bw–BC–C), Dystric Cambisol (O–A or ABv–Bv–BvC–C), Haplic Arenosol and Haplic Podzol (O–AE–Bhs–BC–C). Soils of the CF site are mainly derived from loose sands or weakly loamy sands, and soils of the DCF site from weakly loamy sands or loamy sands as well as light and medium loams (Table 1).

In soils sampled from individual genetic horizons, organic carbon and total nitrogen and their soluble forms were determined. The soil samples were air dried and sieved through a 2 mm mesh. SOC was determined in air dried (20–25 °C) and pulverized

Table 1
Forest type, names of plot, soil and texture type.

Forest type	Name of plot	Soil type	Texture
Coniferous CF	Borecka forest	Haplic Arenosol	Sandy loam
	Goleniowska forest	Haplic Podzol	Sand
	Rajgród	Albic Arenosol	Sand
	Lubsko	Haplic Podzol	Sand
	Tuchola	Albic Arenosol	Sand
	Janów Lubelski	Haplic Podzol	Sand
Deciduous–coniferous DCF	Borecka forest	Eutric Cambisol, Haplic Arenosol	Loam
	Goleniowska forest	Haplic Podzol	Sand
	Rajgród	Dystric Cambisol	Sand or sandy loam
	Miłomłyn	Haplic Arenosol	Sand