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Short communication

Soil temperature is an important regulatory control on dissolved organic carbon supply and uptake of soil solution nitrate

Ehsan R. Toosi [a,*], John P. Schmidt [b], Michael J. Castellano [a]

[a] Department of Agronomy, Iowa State University, Ames, IA, USA
[b] Pasture Systems and Watershed Management Research Unit, Agricultural Research Service, USDA, University Park, PA, USA

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ABSTRACT

The role of abiotic processes on dissolved organic matter (DOM) production is often underappreciated. However, abiotic processes appear to be especially important in subsoils where, with increasing depth, microbial activity declines and soil organic matter (SOM) becomes a progressively more important contributor to DOM. Within three soil depths (20, 40, and 60 cm) in a temperate forest, soil temperature was positively associated with dissolved organic carbon (DOC) concentration (R^2 = 0.23–0.77) and the DOM humification index (R^2 = 0.35–0.72) for soil solutions in slow and fast flowpaths. With increasing soil temperature from 5 to 24 °C, average DOC concentrations increased by 86% at 20 cm, 12% at 40 cm and 12% at 60 cm soil depths. Our data suggest that DOM supply, especially in subsoils, is temperature dependent. We attribute this to the influence of temperature on DOM replenishment through direct processes such as SOM dissolution, diffusion and exchange reactions as well as indirect processes such as rhizodeposition and exoenzyme activity. In contrast, negative relationships (R^2 = 0.71–0.88) between temperature and nitrate concentrations in subsoil suggested that the temperature-dependent supply of DOM drives microbial processes such as dissimilatory and assimilatory nitrate consumption.

1. Introduction

Dissolved organic matter (DOM) is a small but highly dynamic OM pool that links the C cycle among terrestrial, atmospheric, and aquatic systems [13]. Plant tissues (above- and below-ground) and soil organic matter (SOM) are the two primary sources of DOM, but their relative contribution to DOM varies along the soil profile [32,33]. Lysimeters sample DOM representing the residual products of interactions among biological activities and non-biological processes.

Despite the well-established paradigm that suggests extracellular enzymes break down SOM into soluble (assimilable) compounds [24], recent research suggests that in many soil conditions SOM is solubilized primarily as a result of abiotic processes (*e.g.* [12]). This argument (*i.e.* decomposer-substrate disconnection) is based on the poor energy tradeoff of enzymatic OM depolymerization under many soil conditions and specifically the rare occurrence of a combination of favorable soil conditions for activity of a diverse microbial community that is essential for SOM decomposition [1,8,22]. On the other hand, microorganisms and their exoenzymes are not only inherent components of soil, but are largely dormant in most soil conditions. Thus, even when highly reduced, the activities of exoenzymes and decomposer community often with diverse functions (*i.e.* functional redundancy) may still substantially contribute to SOM break down [14]. As a result, it is extremely difficult to directly determine the relative importance of biotic and abiotic processes to SOM solubilization in real soil conditions.

Temperature directly and indirectly regulates DOM production through its influence on biological activities and physico-chemical processes [23,24]. We examined the influence of temperature on the pool size and complexity of DOM and inorganic N in soil solutions primarily associated with fast and slow flowpaths (*i.e.* DOM collected from zero-tension and tension lysimeters, respectively). Sources of DOM and microbial activity vary with soil depth and flowpaths, with fast flowpaths often containing greater proportions of plant-derived DOM (*e.g.* Refs. [5,11,18,34]). Thus, we hypothesized that the influence of soil temperature on DOM pool size and complexity varies with depth and flowpaths such that the effect of temperature is greater in slow flowpaths and subsoils where biological activity is relatively low.

* Corresponding author. Tel.: +1 5152901198; fax: +1 5173533955.
E-mail address: etoosi@msu.edu (E.R. Toosi).

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Table 1
General physico-chemical properties of the soil (data are mean ± STDER; $n = 3$).

Depth (cm)	Texture	TOC[a]	TN[b]	C/N	pH	EC[c]
0–20	Loam	91.9 ± 1.9	4.82 ± 0.3	19.1 ± 0.9	4.7 ± 0.6	0.47 ± 0.06
20–40	Loam	10.8 ± 0.4	0.69 ± 0.06	15.5 ± 1.4	4.8 ± 0.4	0.22 ± 0.03
40–60	Loam	2.6 ± 0.2	0.24 ± 0.04	10.5 ± 1.6	4.7 ± 0.4	0.18 ± 0.03

[a] Total organic C (g kg^{-1}).
[b] Total N (g kg^{-1}).
[c] m mho cm^{-1}.

2. Materials and methods

The study site was located within a long-term research watershed operated by the USDA in Pennsylvania, USA [4]. In 2009, we installed tension and zero-tension lysimeters at 20 (A horizon), 40 and 60 cm (B horizon) depths in a mixed oak-hickory forest that had not been harvested for >50 years. The soil is categorized as Typic Dystrudept. General soil properties are shown in Table 1. Within each of three replicate plots, three subreplicate zero-tension and tension lysimeters were installed along with one moisture-temperature sensor at each depth (Decagon Devices, USA). Within each soil depth, average soil temperature and moisture between each sampling event was used for analyses [16]. Lysimeters were sampled every 10–14 d or after rain events during the sampling period (Mar–Oct 2011), but there were occasions where soil was frozen or too dry. Depending on soil moisture conditions for a given depth, 6 to 14 sampling events were conducted. Tension and zero-tension lysimeters preferentially collect soil solutions that represent different sources and transport kinetics and are primarily associated with slow and fast flowpaths, respectively [5,9,34]. Soil solutions were filtered (0.45 μm), acidified and analyzed for concentration of C (Shimadzu TOC_{CPN}, Japan) and nitrate (Lachat flow injection analyzer). A humification index (HI) was determined as an indicator of the degree of humification based on the DOM fluorescence property [19]. The HI was determined as below using an excitation wavelength of 254 nm and emission range of 300–480 nm (Jobin–Yvon Horiba Fluoromax, Japan):

$$HI = \left(\sum I435 - 480\right) / \left(\sum I300 - 345 + \sum I435 - 480\right) \quad [1]$$

where I is the fluorescence intensity for the given wavelengths. The HI varies from 0 to 1 with higher HI values indicating a larger proportion of humified compounds or an increased degree of humified OM.

All statistical analyses were carried out using SAS 9.2. Linear regression analyses were used to explore across-soil depth relationships between soil temperature and nitrate, DOC, and humification index. Regression lines were shown when $P \leq 0.05$.

3. Results and discussion

3.1. Influence of temperature on DOC, HI, and nitrate

Soil temperature was positively associated with DOC concentration (R^2 = 0.23–0.77, $P \leq 0.05$) and complexity (HI) of DOM (R^2 = 0.35–0.72, $P \leq 0.05$) for both lysimeter types (Fig. 1). Although soil temperature was positively correlated with nitrate sampled from zero-tension lysimeters at 20 cm, it was negatively correlated with nitrate sampled from the tension lysimeters at 40 cm and both lysimeter types at 60 cm. The regression coefficients among these variables were i) higher for DOM sampled

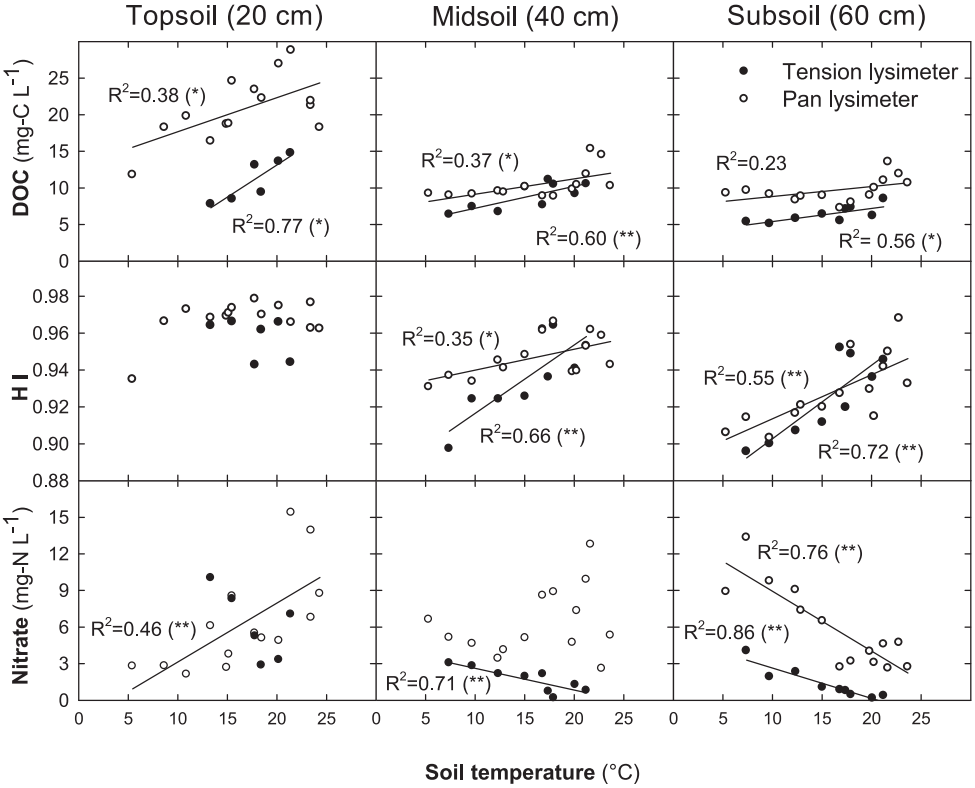

Fig. 1. Regression coefficients between dissolved organic carbon (DOC), humification index (HI) and soil solution nitrate with soil temperature. * and ** indicate P values ≤0.05 and ≤0.01, respectively.