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Effects of moisture and temperature on net soil nitrogen mineralization: A laboratory study

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ABSTRACT

Climate change will lead to changes in soil moisture and temperature, thereby affecting organic matter mineralization and the cycling of biophilic elements such as nitrogen. However, very few studies have considered how the sensitivity of the rate of net nitrogen mineralization to temperature and/or moisture content may be modified by changes in these parameters. To investigate how changes in temperature and moisture content affect net nitrogen mineralization (as regards both the mineralization rate and the sensitivity of the mineralization rate to changes in temperature and moisture content), a laboratory experiment was carried out in which three soils under different types of use (Forest, Grassland, Cropland) were incubated for 42 days under different moisture conditions (between 40 and 100% field capacity) and temperatures (between 10 and 35 °C); total inorganic nitrogen levels were determined at different times throughout the experiment. The rate of mineralization was determined at each temperature and moisture level considered, by use of the mono-compartmental model developed by Stanford and Smith (1972). For all soils, changes in the rate of mineralization with temperature followed the pattern described by the Q_{10} model, while the models used to determine the effect of moisture content on the net rate of mineralization (linear, semilogarithmic, partial parabolic and complete parabolic) were only verified for the Forest soil. In general, the sensitivity to temperature was maximal at 25 °C, and the optimal moisture content for nitrogen mineralization was between 80% and 100% of field capacity. A relatively simple model that included the temperature–moisture–time interaction was also tested. This model provided a significant fit for the three soils under study, in contrast with the other models tested. In any case, further studies are necessary in order to address the extent to which changes in the quality of organic matter, caused by land use, affect any modifications to soil nitrogen that may be generated by climate change.

1. Introduction

Climate is changing on a global scale and affecting soil temperature and moisture regimes [1]. Climate change will therefore also affect all edaphic processes that depend on soil temperature and moisture, including soil organic matter mineralization [2,3]. There has been great interest in the possible effects of climate change on soil carbon cycling and on CO_2 emissions [4,5]. There are two main reasons for this interest. Firstly, as CO_2 is one of the main greenhouse gases (i.e. it is capable of affecting climate change), it is essential to understand the feed-back mechanisms between climate change and CO_2 emissions. Secondly, measurement of CO_2 emissions is a straightforward, rapid method of determining the impact of climate change on edaphic metabolism [4].

However, carbon is not the only element affected by climate change, and elements such as nitrogen, phosphorus and sulphur, typically associated with organisms, are also affected. All of these are essential elements and are therefore extremely important for the correct functioning of ecosystems. In the case of nitrogen, most bioavailable forms of this element in natural soils are produced by mineralization of organic matter via depolymerization of large organic polymers, so that the productivity of many ecosystems will depend directly on the availability of nitrogen derived from the decomposition of organic remains. It is therefore reasonable to assume that any modification that affects the rate of decomposition of organic matter will also affect the availability of nitrogen, and therefore will have important repercussions for ecosystem functioning [6].

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Many studies involving mineralization of organic nitrogen compounds in soil have been undertaken since the early studies in 1972 by Stanford and Smith, as reported by Dessureault-Rompré et al. [7]. Stanford and Smith [8] demonstrated that net nitrogen mineralization followed first order kinetics and that the effect of temperature on nitrogen mineralization followed the Arrhenius law, with the rate doubling for each 10 °C increase in temperature. Various authors have recently discussed the effects of temperature and/or moisture content on the net mineralization process, as well as how soil moisture should be expressed (percentage of pore filled, water potential, etc.) and how the different mathematical models used to study such relationships should be interpreted [2, 7, 9, 10, 11, amongst others]. Most of these studies have focused on the rate of nitrogen mineralization, with the aim of estimating the amount of nitrogen that is available to plants. In other words these studies had an agronomic focus. Nevertheless, very few studies about soil nitrogen mineralization consider the sensitivity of the mineralization rate to changes in temperature and moisture with the aim of determining the direct impact of climatic parameters on the nitrogen cycle [7]. This is an important omission as more accurate information about the sensitivity of mineralization constants and how they vary in relation to climatic parameters would enable better description of the response of soil organic matter to climate change. Furthermore, there is even less information about the combined effects of these two factors (temperature and soil moisture) on net nitrogen mineralization processes [11–13], despite evidence that climate change will affect both components of the climate simultaneously, as indicated above. In fact, Craine and Gelderman [14] indicated their surprise about the scarcity of information as to how soil moisture affects the temperature sensitivity of soil organic matter decomposition and whether or not any such relationships are consistent across different soils.

At present the climate in Galicia (NW Spain) is humid temperate and, because of its geographical position (north of 40° N), the region is expected to undergo significant changes [1]. It is therefore important to predict the response of soils to such changes, and to establish which types of soils (in terms of management regimes) will be most affected. Recent laboratory and field studies in Galicia have addressed the issue of how CO_2 emissions in soils will be affected by climate change [15]. The thermodynamic properties of several edaphic enzymes (both hydrolases and oxidoreductases) have also been characterized in order to establish how decomposition processes mediated by these enzymes would be affected by changes in soil temperature [16]. However, to date the effects of climate change on nitrogen mineralization have not been analyzed in Galician soils. Therefore, and given the general lack of knowledge about the influence of climate changes on net nitrogen mineralization, the objectives of the present study were: a) to investigate how net nitrogen mineralization is modified in response to changes in temperature or moisture, b) to determine the extent to which land use modifies the sensitivity of net nitrogen mineralization to changes in soil temperature and moisture, and c) to investigate the extent to which climate change will affect nitrogen availability in Galician soils.

2. Materials and methods

2.1. Soils, soil sampling and soil preparation

Three soils (Forest, Grassland and Cropland) were selected as representative of Galician soils under different types of land use. The forest soil (Forest) is an *Umbrisol* under Atlantic oak, which is the *climax* vegetation in Galicia. The grassland soil (Grassland) is also an *Umbrisol* but subjected to intensive grassland use and represents intensively managed grassland soils, derived more than 40 years ago from former forest soils, and fertilized intensively every year, mainly with cattle slurry (200–250 kg nitrogen ha^{-1} $year^{-1}$). Finally, the cropland soil (Cropland) is an *Umbrisol* partially degraded by intensive use, which represents the characteristic type of agricultural soil found close to houses in rural areas of Galicia, and cultivated throughout the year by crop rotation and intense application of both organic (manure) and inorganic (NPK) fertilizers (approximately 150 kg of nitrogen ha^{-1} $year^{-1}$). The location and the main physical and chemical characteristics of each of the soils are shown in Table 1.

The upper 10 cm of each of the soils (A horizons) were sampled. Sampling was carried out after a period of more than 20 days without precipitation (so that the soils were as dry as possible and could be watered to produce the different moisture contents required), and at least one month since the last agricultural treatments in the Grassland and Cropland soils (to minimize the possibility that any responses were not affected by agricultural activities). In the laboratory, the soils were sieved (<4 mm), the fine roots were removed (manually) and the soils were homogenized. The moisture content was determined by gravimetry, in an aliquot of moist soil dried at 105 °C for 24 h. The soils were then placed in plastic bags and stored at 4 °C until the start of the incubation experiment. An aliquot of each soil was used to determine the water retained at −33 kP pressure (field capacity), with a tension plate apparatus [17]. Another aliquot of each soil was air-dried and used for the general analyses outlined further below.

2.2. Incubation procedure and laboratory measurements

The effect of temperature and moisture on soil organic nitrogen mineralization was investigated in a laboratory incubation experiment of 42 days duration. Aliquots of each of the soils (equivalent to 500 g of oven dry soil) were wetted with distilled water to produce different moisture levels. In the Forest and Grassland soils, four moisture levels (40, 60, 80 and 100% field capacity) were considered (corresponding to 34, 51, 68 and 85 g H_2O 100 g^{-1} soil for the Forest soil, and 24, 36, 48 and 60 g H_2O 100 g^{-1} soil for the Grassland soil).

Table 1
Main site characteristics and physicochemical properties of the soils used in the study. Estimated values of potentially mineralizable nitrogen (N_o), expressed as absolute values (mg N kg^{-1} soil) as well as per unit of carbon (mg N g^{-1} total C) and total nitrogen (mg N g^{-1} total N). Numbers in the same row followed by the same letter are not significantly different ($P < 0.001$).

Soil	Forest	Grassland	Cropland
Site characteristics			
Main plant species	*Quercus robur* L.	*Lolium multiflorum* Lam	*Zea mays* L.
Soil parent material	schists	granodiorites	granodiorites
Longitude	8° 21′ 30″ W	8° 42′ 30″ W	8° 42′ 35″ W
Latitude	42°36′ 58″ N	42° 59′ 00″ N	42° 59′ 10″ N
Elevation (m.a.s.l.)	645	320	315
Soil type (FAO)	*Umbrisol*	*Umbrisol*	*Umbrisol*
Physicochemical soil properties			
Soil pH (in water)	4.81	5.43	5.01
Total C (%)	8.82	8.26	5.22
Total N (%)	0.88	0.70	0.47
C/N	10	12	11
Clay content (%)	24	17	20
Soil texture	sandy loam	sandy loam	sandy loam
Field capacity (g H_2O g^{-1} soil)	0.85	0.60	0.42
Potentially mineralizable nitrogen (N_o)			
mg N kg^{-1} soil	347a	400a	167b
mg N g^{-1} total C	3.93a	4.84b	3.20c
mg N g^{-1} total N	39.6a	57.3b	35.8a