European Journal of Soil Biology 62 (2014) 66–73

Contents lists available at ScienceDirect

European Journal of Soil Biology

journal homepage: http://www.elsevier.com/locate/ejsobi

Original article

The response mechanisms of soil N mineralization under biological soil crusts to temperature and moisture in temperate desert regions

Rui Hu [a], Xin-ping Wang [a,*], Yan-xia Pan [a], Ya-feng Zhang [a,b], Hao Zhang [a,b]

[a] Shapotou Desert Research and Experiment Station, Cold and Arid Regions, Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou, Gansu 730000, China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 24 June 2013
Received in revised form
19 February 2014
Accepted 24 February 2014
Available online 19 March 2014
Handling editor: Christoph Tebbe

Keywords:
Biological soil crust
N mineralization
Temperature
Moisture

ABSTRACT

Soil nitrogen (N) mineralization is an important component of the N cycling process in desert ecosystems. However, the effects of biological soil crust (BSC), especially different patterns of BSCs (i.e. moss, algae-lichen), on net nitrification and N mineralization rates under climate-change conditions are still largely unexplored. To investigate the effects of temperature and moisture on net nitrification and N mineralization rates in BSC-dominated desert soils, and to highlight the regulatory role of BSC on N availability in the Tengger Desert, China, intact soil cores from three microhabitats (moss-covered, algae-lichen-covered, and bare soil) were incubated at six temperatures (−10, 5, 15, 25, 35, and 40 °C) and four moisture levels (29, 58, 85, and 170% field water content, FWC). Generally, moss-covered soil exhibited the highest net N transformation rate, whereas, algae-lichen-covered soil inhibited the nitrification process. Incubation temperature and moisture significantly affected net nitrification and N mineralization rates in all three microhabitats, in general that values were higher at the higher temperature (i.e. 25, 35, and 40 °C) compared to lower temperature (i.e. −10, 5, 15 °C). The net N mineralization rate for the three microhabitats peaked at 85% FWC. Overall, results indicated that BSCs, especially moss-dominated soils, increase net N transformation rate and N availability. Thus, they can make a contribution to plant growth and play a positive role in primary productivity under climate change in arid areas.

1. Introduction

Nitrogen (N) is a key element in nutrient cycling and its bioavailable forms are produced by mineralization, which depolymerizes organic N into inorganic N. As the main limiting factor for plant growth and net primary productivity in many terrestrial ecosystems [1–3], soil N availability and its responses to environmental factors are critical for the development of ecosystems and global carbon (C) budgets [4]. Climate change is expected to cause important changes in temperature and rainfall for drylands, including more frequent and intense rainfall events, increase in extreme events, such as high temperatures, frequent heat waves and intense droughts, decrease in extreme low temperatures [5]. These expected changes will also change the soil temperature and moisture regimes that influence edaphic processes such as soil organic matter mineralization [6]. Accordingly, studies of interactive effects of temperature and moisture on soil N mineralization will improve the understanding of N dynamics for a coming climate change.

Temperature and moisture are the two major environmental factors controlling the activity of microorganisms in soil, which in turn influence net N transformation rates (nitrification and N mineralization) [7]. Much recent research has investigated mathematical modeling of relationships between N transformation and environmental factors. Pansu and Thuriès [8] used a Transformation of Added Organics (TAO) model to predict N transformation and immobilization; Gil et al. [9] compared five mathematical models, using experimental data of mineralized N accumulated during 360 and 720 days of incubation. They showed that as the experimental time increased from 1 to 2 years, a special model proved more accurate than a simple exponential model in explaining the N mineralization kinetics in compost-amended soil. Moreover, Sleutel et al. [10] discussed relationships between N mineralization and soil moisture content in loamy to silty textured soils by using hydro-ecological models. Multiple linear regressions between N mineralization and general soil parameters indicated that soil structure has an overriding impact on N mineralization in wetland ecosystems. Most of these studies focused on the kinetics

* Corresponding author. Tel./fax: +86 9314967185.
E-mail address: hurui22831@163.com (X.-p. Wang).

http://dx.doi.org/10.1016/j.ejsobi.2014.02.008
1164-5563/

of N transformation. However, few studies have considered the response of N mineralization rate to changes in temperature and moisture, to determine the direct impact of climatic parameters on the N cycling [11,12]. Moreover, there is even less information on the interactive effects of temperature and soil moisture on the net N mineralization process. A better knowledge in this respect would improve our understanding of the response of soil N transformation to climate change.

Biological soil crust (BSC) is the diminutive organisms associated with soil particles, such as algae, cyanobacteria, lichens, and mosses. BSC is widely distributed in arid and semi-arid landscapes all over the world, accounting for 40% of the total terrestrial surface [13–15]. The succession of BSC in desert ecosystems after disturbance and dune stabilization is usually considered to be a course in which the pioneer cyanobacteria are gradually replaced by desert algae, lichens, and mosses [16,17]. As unique ecosystem engineers, BSC is known to play various important ecological roles [18], including prevention of soil erosion [19,20], enhancement of soil stability and modulation of water fluxes through their effects on runoff and infiltration [21,14], and modification of soil temperature and moisture [22,23]. Furthermore, BSC can significantly modify the N cycling [24–26], such as N fixation, and this has recently been shown to be a critical N source in drylands [26,27]. Although, the importance of BSC in N cycling of arid and semi-arid ecosystems has been recognized, only few studies have shown the release and availability of N [24,28]. Furthermore, the influences of environmental factors such as soil temperature and moisture on N transformation rates under BSC are still poorly understood [29]. Delgado-Baquerizo et al. [30] studied the effects of temperature and moisture on N transformation under BSC and bare ground microsites. N transformation under BSC was observed at the highest soil water content, regardless of temperature. Thus, the maintenance of well-developed BSC communities can minimize the negative impact of expected increase in temperature variability by climate change on important N cycle variables. However, our knowledge on the influence of temperature, soil moisture, and their interaction on soil N transformation under BSC, especially different patterns of BSCs (e.g., moss and algae-lichen) in temperate deserts, is still limited. Few studies have so far assessed the role of BSC in ecosystem N dynamics. Especially, the effects of climate change on N transformation with different BSC patterns are still missing [31].

Table 1
Description of the three soil microhabitats in the study area.

Type	Habitat characteristic
Moss-covered soil	Dominated by about 15 mm thick moss on its surface with a deep-green color in the rainy season and a brown color in the dry season. The primary species are *Bryum argenteum* Hedw., *Didymodon constrictus* (Mitt.) Saito., *Tortula bidentata* Bai Xue Liang and *T. desertorum* Broth [62]. Neither shrubs nor herbs existed on the moss-covered soils.
Algae-lichen-covered soil	Dominated by cyanobacteria, algae and lichen on its surface, about 2–3 mm in thickness, and with primary species *Microcoleus vaginatus* Gom., *Hydrocoleus violacens* Gom., *Lyngbya crytoraginatus* Schk., *Phormidium amblgum* Gom., *P. autumnale* (Ag.) Gom., *P. foveolarum* (Mont.) Gom., *Phormidium luridum* (Kutz) Gom. *Collema tenax* (Sw.) Ach., *Endocarpon pusillum* Hedw. and a few *Squamarina lentigera* (G.H. Weber) Poelt, *Diploschistes muscorum* (Scop.) R. Sant [61,62]. They were fragile and a few seedlings of herbs grew in crevices.
Bare soil	The surface with white color was less than 1 mm thick sheets appearing between the shrubs without any cryptogams or herbs. These sheets were intact but easily broken if touched.

In this study, we evaluated how temperature, moisture, and their interactions influence the transformation rates under BSC-covered soils and examined the response of N transformation rates for different BSC types (moss and algae-lichen). Previous studies have suggested that soil mineralization rate should increase with temperature increase, while nitrification rate may increase with temperature increase for moderate soil water content [32,33]. However, the response of N transformation rates for these environmental factors under BSC has not yet been studied extensively [29,34]. We hypothesize that increasing temperature and moisture will stimulate the availability of soil N transformation rates, but depending on crust types. Drawing upon previous studies, which showed that N mineralization is positively correlated with soil C and N concentration [24,25,35], we test the hypothesis that BSCs, especially moss-covered soils will increase the soil N transformation rates since they are the late-successional stage crusts that can improve soil properties such as increasing C and N inputs, accumulating organic matters, promoting nutrition availability and cycling in soils [36,37].

2. Materials and methods

2.1. Study area

This study was performed in the Shapotou area, at the southeastern edge of the Tengger Desert in northern China (37°25′N and 104°36′E) at 1339 m a.s.l. The area is a steppe desert zone ecotone between desertified steppe and sandy desert [38]. The average annual temperature is 10.6 °C, and average monthly temperatures are 24.9 °C in July and −6.3 °C in January. Mean annual precipitation is 191 mm, 80% of which occur between July and September. The potential evapotranspiration is about 2500 mm during the growing season (April to October). The windy season is April to September and average wind velocity is 3.5 m/s. The dominant natural vegetation is *Artemisia ordosica* Krasch and *Caragana korshinskii* Kom. Open areas between plants patches contain different microhabitats dominated by various cryptogams.

2.2. Experimental design

Twelve 0.5 × 0.5 m plots 2–3 m apart were randomly selected in three microhabitats dominated by moss, algae-lichen and bare soil free of cryptogams, respectively. The detailed habitat characteristics are shown in Table 1. During 17–22 July, 2010, 6 paired soil cores, 10 cm deep and 5 cm apart, were taken from each plot using PVC cylinders 15 cm long × 5 cm diameter after removing the litter. One core of each pair was used to measure initial $NH_4^+ - N$ and $NO_3^- - N$ content and other was incubated with 13 h illumination per day in the laboratory [39]. To reflect the response of N transformation to the various observed temperatures and also to mimic influence of a future climate change on N transformation, we set six temperatures (−10, 5, 15, 25, 35, and 40 °C), and four rainfall amounts (5, 10, 15, and 30 mm) were used to emulate local climatic conditions. To simulate rainfall, distilled water was sprayed on the plots using a small hand-held sprayer. After rainfall simulation, soil moisture corresponded to 29, 58, 85, and 170% of field water capacity (FWC), respectively. In order to keep soil moisture constant during the incubation time, the samples were kept in a closed chamber. The chamber was closed with polyethylene film allowing for gas exchange, but avoiding water losses. To keep soil moisture constant, we monitored the soil water content by weighing the chamber during the incubation process. All samples were incubated for 14 days at each temperature. Thus, 216 incubated soil samples (3 soil types × 6 temperatures × 4 rainfall amounts × 3 replicates) were prepared along with 216 non-incubated soil