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Impact of human trampling on biological soil crusts determined by soil microbial biomass, enzyme activities and nematode communities in a desert ecosystem

Hangyu Yang[a,b], Changzhong Liu[a,**], Yanmei Liu[c,d,*], Zisheng Xing[e]

[a] College of Grassland Sciences, Gansu Agricultural University, Lanzhou 730070, China
[b] Gansu Forestry Technological College, Tianshui 741020, China
[c] The Key Discipline of Microbiology in Gansu Province, School of Biological Engineering and Technology, Tianshui Normal University, Tianshui 741001, China
[d] Shapotou Desert Research and Experiment Station, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China
[e] AAFC-Portage, Brandon Research and Development Center, MB, Canada

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ABSTRACT

Human activities disturb Biological soil crusts (biocrusts) in desert areas throughout the world. To assess the effects of trampling on biocrusts and its consequence on sandy soil quality, soil beneath trampling to early-successional cyanobacteria–lichen crusts and late-successional moss crusts was served as the research object in vegetation areas of the Tengger Desert. Trampling intensity was divided into non-trampling, medium trampling and severe trampling of biocrusts. We analyzed changes in soil microbial biomass, enzyme activities and nematode communities one year after trampling biocrust. The results showed that trampling biocrusts reduced soil microbial biomass carbon (C) and nitrogen (N), lowered soil urease, invertase, catalase and dehydrogenase activity, as well as reduced soil nematode abundance, generic richness, Shannon–Weaver index (*H′*) and Maturity index (MI) in the study areas, and severely-trampled biocrusts caused a strong decline in these parameters ($p < 0.05$). The declined soil available phosphorus (P), available N, total N and P may be the major factors that cause the observed reduction in soil microbial and nematode parameters. Impact was correlated with trampling intensity or successional stages of biocrusts. The studied soil microbial and nematode parameters were negatively correlated with trampling intensity. Furthermore, soil microbial biomass, the four enzyme activities, nematode abundance and generic richness were significantly greater underneath trampled/untrampled moss crusts than corresponding trampled/untrampled cyanobacteria-lichen crusts, indicating late-successional crusts have a higher tolerance to trampling disturbance compared to early-successional crusts. Overall, these results suggest that trampling biocrusts lead to a degradation of sandy soil quality in desert ecosystems.

1. Introduction

Biological soil crusts (biocrusts) are associations of soil organisms (mainly cyanobacteria, bryophytes, algae, lichens, microfungi and bacteria) and soil particles [1]. They are ubiquitous and extremely important in arid and semiarid areas, which occupy more than one-third of the earth's terrestrial surface [9,53]. Biocrusts constitute up to 70% of the living cover on arid soils [19] due to their ability to withstand high temperatures, strong radiation, low nutrient conditions, low water potential and to remain dormant for long dry periods in drylands [44]. Stabilizing soil and enhancing soil fertility are the most important ecological functions of biocrusts in many drylands [8,21]. However, soil surface disturbance by footprints, hoof prints and vehicle tracks may cause significant damage to biocrust communities [25], which are highly susceptible to soil surface disturbances [9,14,54], leading to the degradation of biocrusts' ecosystem functions [13]. A number of studies have reported that trampling disturbance reduces biocrust biomass, coverage and species diversity, transforming late-successional crusts to early-successional crusts, which leads to accelerated soil erosion, reduced water infiltration, soil C and N loss, and alteration of soil temperature and aeration [3,6,7,9,17,19,22,23,26].

Soil microbes drive many ecological processes in soil, such as mineral weathering, organic matter decomposition and nutrient cycling, and so doing they can respond rapidly to environmental changes and

* Corresponding author. The Key Discipline of Microbiology in Gansu Province, School of Biological Engineering and Technology, Tianshui Normal University, Tianshui 741001, China. Tel.: +8613830836266.
** Corresponding author.
E-mail addresses: liuchzh@gsau.edu.cn (C. Liu), lym-781118@163.com (Y. Liu).

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human activities [55]. Apart from microbes, soil nematodes are ubiquitous inhabitants of soil with important ecosystem functions and they are important indicators for soil monitoring [24]. Therefore, by studying soil microbes and nematodes which are affected by trampled biocrusts we can assess the changes in soil quality as a result of trampling and further predict the development status of desert ecosystems and the effectiveness of management interventions on desert ecosystems.

Many studies have documented changes in soil microbial and nematode parameters in response to above-ground disturbance of biocrusts. For instance, Bates et al. [4] and Belnap [5] demonstrated that fungal diversity and nitrogenase activity in lichen-dominated crusts were both negatively correlated with the intensity of biocrust disturbance. Kuske et al. [33] and Steven et al. [50] found that soil microbial communities were markedly changed by foot trampling. Liu et al. [38] found that severe trampling of biocrusts in desert areas reduced soil basal respiration and activities of soil alkaline phosphatase, protease and cellulase, as well as enhanced qCO_2. Darby et al. [15] showed that trampling biocrusts decreased soil nematode abundance, richness and diversity in the Colorado Plateau. Furthermore, the impact of disturbed biocrusts on soil microorganisms may vary according to the successional stages of biocrusts. Belnap [5] reported that soil nitrogenase activity after vehicle disturbance was less disrupted in late-stage crusts than in early-stage crusts. However, improved understanding of the impact of trampled biocrusts on soil microbial biomass, enzyme activities and nematode communities as critical parameters for exploring the function of biocrusts in desert ecosystems is scarce. Also, the influence of successional stages of biocrusts following trampling on soil microbial biomass, enzyme activities and nematode communities is poorly understood in desert ecosystems.

Our objectives were to determine (1) the impact of trampling intensity on soil microbial biomass, enzyme activities and nematode communities; (2) how soil microbial biomass, enzyme activities and nematode communities differed with successional stages of biocrusts following trampling, and (3) the relationship between soil microbial and nematode parameters and soil physicochemical factors following trampling. Predicting the impact of biocrusts following trampling on soil quality in desert areas, could provide important information for estimating biocrusts function and a theoretical basis for management of degraded desert ecosystems.

2. Material and methods

2.1. Site description

The research site, which consists of artificial and natural vegetation areas, is located at the southeast fringe of the Tengger Desert in northern China (37°32′N, 105°02′E, and 1339 m above sea level). The area acts as a transitional zone between sandy bare and revegetated deserts [42]. The climate is semiarid with a mean precipitation of $\sim 186\ mm\ yr^{-1}$ which falls primarily from May to September. The average potential evaporation during the growing season is $\sim 3000\ mm\ yr^{-1}$. The average air temperature is 9.6 °C, reaching a mean maximum temperature of 24.3 °C in July and a mean minimum temperature of −6.9 °C in January. The barren and mobile soil is classified as typical sierozem and aeolian sandy soil with very low water content of 3%–4% and organic matter content of 1.5–4.0 $g\ kg^{-1}$ [37,41]. Rainfall is the main water source in this desert region because groundwater is located 80 m below the surface and cannot be accessed by native vegetation.

To prevent the sustained expansion of the Tengger Desert and to protect the Baotou-Lanzhou railway from sand burial, a non-irrigated vegetation system was established in 1956, 1964, 1981, and 1991 using straw-checkerboard sand barriers to initially fix mobile dunes and subsequent planting of xerophytic shrubs, *Artemisia ordosia* Krasch, *Caragana korshinskii* Kom. and *C. microphylla* Lam. [39,43]. Biocrusts colonized these areas following surface stabilization and now cover more than 80% of the revegetated desert region. These areas are called the artificial vegetation areas. The natural vegetation areas were located at Hongwei, 22 km from the artificial vegetation areas, and they are characterized by undisturbed native vegetation. There are the same climate, landscape and soil type as the artificial vegetation areas in the sites. The dominant plant species include shrubs and semi shrubs (*Ceratoides lateens* (J.F. Gmel) Reveal et Holmgren, *A. ordosica* Krasch, *C. korshinskii* Kom., *Hedysarum scoparium* Fisch., and *Oxytropis aciphylla* Ledeb.) and grasses (*Allium mongolicum* Regel, *A. capillaris* Thunb., *Chloris virgata* Sw., and *Bassia dasyphylla* (Fisch. et. Mey.) O. Kuntze) with a cover of 20%–45% [40]. The average coverage of biocrusts is more than 50% of the natural vegetation areas [46]. Moreover, succession from early-to late-stage crusts has occurred, and coexistence of cyanobacteria-lichen dominated crusts as the early-successional stage, and moss-dominated crusts as the late-successional stage, are apparent with similar succession degree in both artificial vegetation areas and natural vegetation areas.

2.2. Soil sample design and collection

The artificial vegetation areas of 1956 and natural vegetation areas at Hongwei were chosen as experimental locations. In July 2013, we randomly selected five areas with a size of 10 m × 10 m containing both cyanobacteria-lichen dominated crusts and moss-dominated crusts, where enclosures (1 m × 1 m) with a high crust coverage (> 90%) were established parallel to the Baotou-Lanzhou railway, with at least 5-m spacing between two adjoining plots as untrampled control areas. To the south side of each plot with similar biocrust characteristics (e.g., types, thickness and coverage) as untrampled control areas, ten 1 m × 1 m plots were established and treated by severe-trampling or medium-trampling. Trampling was performed on a single day by two people each weighing 60 kg wearing lug-soled boots who walked on dry crust surfaces, as referenced by Ref. [32]. Trampling was categorized according to intensity of trampling: severe-trampled biocrusts (the percentage of untrampled crust coverage in a plot area < 35%), medium-trampled biocrusts (the percentage of untrampled crust coverage in a plot area = 35%–65%) and untrampled biocrusts (the percentage of untrampled crust coverage in a plot area > 65%) for both the artificial and natural vegetation areas. Severe-trampled cyanobacteria-lichen crusts, medium-trampled cyanobacteria-lichen crusts and untrampled cyanobacteria-lichen crusts were referred to as St-early, Mt-early and Ut-early, respectively. Similarly, severe-trampled moss crusts, medium-trampled moss crusts and untrampled moss crusts were referred to as St-late, Mt-late and Ut-late, respectively. One year after trampling, the upper crusts layers were extracted and soil samples were collected from two different soil depths (surface layer: 0–5 cm and deep layer: 5–15 cm) by using a 5 cm inner diameter soil auger within each plot. Each soil sample under the similar trampling intensity was collected and mixed after taken from five plots as five replicates with the same soil depth and successional stage of biocrusts. Also, five replicates of soils under both the early- and the late-successional stages of biocrusts with the same soil depth and trampling intensity were collected from five plots.

Composite soil samples were placed in individual plastic bags and taken back to the laboratory. Soil samples were sieved through a 2-mm mesh to remove roots and stones, and then divided into three subsamples. A portion of the composite sample was air-dried for analysis of soil physical and chemical properties; the second portion was immediately used to extract soil nematodes, and the remainder was stored at 4 °C for soil microbial biomass and enzyme activity analyses.

2.3. Analyses of soil physicochemical properties

To determine soil moisture, 30 g soil samples were dried at 105 °C for 24 h. Soil pH was measured using a glass electrode in 1:5 soil:water