European Journal of Soil Biology 74 (2016) 93–103

Contents lists available at ScienceDirect

European Journal of Soil Biology

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

Original article

Biocrusts, inside and outside resource islands of *Mimosa luisana* (Leguminosae), improve soil carbon and nitrogen dynamics in a tropical semiarid ecosystem

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ARTICLE INFO

Article history:
Received 22 October 2015
Received in revised form
11 February 2016
Accepted 16 March 2016
Available online 1 April 2016

Handling Editor: C.C. Tebbe

Keywords:
Biological-soil-crusts
Legumes
Soil nutrients
Soil fertility
Soil biology
Thorny-tropical scrub

ABSTRACT

In the semiarid Valley of Zapotitlán Salinas, Puebla, Mexico, biocrusts may be found inside *Mimosa luisana* Brandegee (Leguminosae)-resource islands (RI) or outside them (ORI). We studied the seasonal variation of the effect of three microenvironments: *i*) *M. luisana*-RI + biocrusts (Biocrusts-RI), *ii*) biocrusts outside *M. luisana*-RI (Biocrusts-ORI), and *iii*) Open areas (OA), on the soil C and N dynamics. In both rainy and dry seasons, moss species richness and cover were higher at Biocrusts-RI than in Biocrusts-ORI; opposite pattern to lichens. Soil organic C, labile C, and total N were the highest at Biocrusts-RI, intermediate at Biocrusts-ORI, and lowest at OA. This agrees with high microbial C and N, and C mineralization. We suggest that C availability regulated soil N availability under both Biocrusts-RI and Biocrusts-ORI by stimulating microbial biomass and N mineralization. Biocrusts-RI and Biocrusts-ORI did not differ in soil NH_4^+ and NO_3^- concentration, but N mineralization was higher at both microenvironments than in OA in the dry season. In contrast, in the rainy season, nitrification was higher and decreased from OA, Biocrusts-ORI to Biocrusts-RI. It supports that both Biocrusts-RI and Biocrusts-ORI may be forming "mantles of fertility", and highlight their functional role on microbial dynamics and N transformations linked to changes in C availability, providing a hypothetical model for a better understanding of soil biology within this tropical semiarid ecosystem.

1. Introduction

Arid and semiarid ecosystems are highly heterogeneous due to rainfall seasonality [1] and spatial variability created by the existence of vegetation patches with different sizes and forms [2], and isolated plants creating resource islands (RI), which redistribute soil resources (i.e. soil nutrients, and water) and improve microenvironmental conditions [3]. Understanding how spatial and temporal heterogeneity affect the functioning of these ecosystems is critical to formulate frame-works for their conservation, management or restoration. These ecosystems cover *ca.* 41% of the global terrestrial surface, and 60% in Mexican territory, but are highly disturbed [4].

Current research [5–10] have demonstrated that legumes as some *Mimosa* and *Prosopis* species form RI, whose soil contains higher amounts of organic material, which promotes the microbial activity, enabling the soil nutrients availability compared to bare soil. In addition, the legume-RI also provides a more benign microenvironment that reduces temperature and increases humidity, promoting strong plant-soil-microorganisms feedbacks, as well as the establishment of other plants under their canopies [3,5–7]. Recently, on the soil of legume-RI such as those formed by

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http://dx.doi.org/10.1016/j.ejsobi.2016.03.006
1164-5563/

Mimosa luisana Brandegee, the presence of communities constituted by cyanobacteria, lichens and mosses (biocrusts) has also been observed; although, they can also be found outside *Mimosa luisana*-RI [11], where they also contribute to soil fertility, protection against rainfall water run-off and wind erosion, as in other dry ecosystems [12].

As it occurs in the legume-RI, but in a micro-scale, it has also been shown that biocrusts are able to build a favorable soil microenvironment for other organisms; enhancing rainfall water infiltration and soil water availability [13], and improving soil carbon (C) and nitrogen (N) dynamics [14–16,24]; hence increasing the nutritional status of plants and microorganisms [12], and facilitating seed germination [17–19]; consequently, promoting plant growth and establishment under environmental adverse conditions [12,19]. In Mexico, most of the studies have been focused on species composition and distribution of biocrusts in relation to soil in both undisturbed [11,20–22] and disturbed conditions [23,24], keeping on the side functional aspects; for instance, the effect of biocrusts on biological C and N transformations in the soil.

It is already known that some *Mimosa* species-RI, including *M. luisana*-RI, have a forestry insularity effect on soil nutrients that is defined by a decreasing gradient from species-trunk soil, with the highest C and N concentrations, towards species-mid-foliage cover soil/species-edge-foliage cover soil, to the soil of open areas with the lowest concentrations [7]. This insularity gradient may also be due to the relationship between *M. luisana* and biocrusts under the canopy of this legume. In addition, this plant could be altering biocrust constituents in relation to areas outside RI, as it has been reported in biocrusts under the canopy of others desert plants [11,13,25], changing thus nutrients cycling [14,15,26]. However, there are no studies focused on the functional role of both *M. luisana*-RI and biocrusts on soil C and N dynamics in semiarid ecosystems. In turn, we hypothesized that biocrusts inside *M. luisana*-RI would differ in species composition and cover from biocrusts outside, so they may differentially influence the availability and biological transformations of subsurface soil C and N, in relation to open area soils, especially during the rainy season, when biocrusts are metabolically active. Actually, there is a critical gap in relation to the understanding on how biocrusts could regulate the activity of different soil microbial groups, impacting C and N dynamics [1,12,15], especially in tropical semiarid ecosystems.

Therefore, the aim of this study was to determine the effect of three microenvironments: *i*) Biocrusts inside *M. luisana*-RI (Biocrusts-RI), *ii*) biocrusts outside *M. luisana*-RI (Biocrusts-ORI), and *iii*) Open areas (OA), on the availability-mineralization of soil C and N, in dry and rainy seasons, in the tropical semiarid Valley of Zapotitlán Salinas, within the Tehuacán-Cuicatlán Biosphere Reserve, Puebla, Mexico.

2. Material and methods

2.1. Study area

The Valley of Zapotitlán Salinas (18°20′N, 97°28′W), Puebla, Mexico, is part of the Tehuacán-Cuicatlán Biosphere Reserve (Fig. S1). Climate is semiarid, with an average annual temperature of 21 °C and an annual rainfall ranging from 400 to 600 mm [27]. Soils are sandy-clay-loams (41% sand, 37% silt, and 22% clay), poor in its structure, mainly derived from sedimentary and metamorphic rocks, and classified as Calcisols in the FAO/UNESCO system [28]. The dominant vegetation type is the tropical thorny scrub, where the most abundant species are *M. luisana*, *Prosopis laevigata* (Humb. & Bonpl. ex Willd.) MC. Johnston, *Parkinsonia praecox* (González-Ruiz and Pavón) Harms., *Myrtillocactus geometrizans* (Mart.) DC., and *Neobuxbaumia tetetzo* (Weber) Backeb., among others [29]. *M. luisana* is a shrub of 1–4.5 m tall, with foliage cover up to 6 m^2, endemic to the Tehuacán-Cuicatlán region, where 16 *Mimosa* species have been recorded [30]. This plant species is either dominant or co-dominant in plant communities [5], and is used by local people as wood fuel, construction or in traditional medicine; hence it is consider as a multipurpose species [31].

2.2. Sampling design

Within the Valley of Zapotitlán Salinas, seven plots were distributed in different locations: **P1**: 18° 18′ 42.0″ N, 97° 32′ 32.1″ W (1615 m asl); **P2**: 18° 18′ 16.4″ N, 97° 32′ 32.3″ W (1580 m asl); **P3**: 18° 17′ 55.0″ N, 97° 31′ 21.5″ W (1578 m asl); **P4**: 18° 17′ 9.0″ N,97° 29′ 52.7″ W (1590 m asl); **P5**: 18° 19′ 44.6″ N, 97° 27′ 24.1″ W (1509 m asl); **P6**: 18° 19′ 36.9″ N, 97° 27′ 20.7″ W (1460 m asl); and **P7**: 18° 17′ 55.0″ N, 97° 31′ 21.5″ W (1455 m asl). Every plot measured 1000 m^2 (20 m × 50 m); when possible, it was established in a flat site; otherwise, the slope was ≤10° (Fig. S1). Per plot, three independent microenvironments were selected: *i*) Biocrusts inside RI formed by *M. luisana* (2–3 m height, and 4–5 m foliage cover) (Biocrusts-RI), *ii*) Biocrusts outside RI (Biocrusts-ORI), and *iii*) Open areas, without plants or biocrusts (OA) (Fig. S2). Biocrusts, litter and soil samples were collected in two seasons: *i*) Dry (March), and *ii*) Rainy (September) on points randomly distributed at each plot.

Biocrusts samples were collected of the microenvironments Biocrusts-RI and Biocrusts-ORI, at 15 points per plot, and they were placed in sterile Petri dishes sealed with parafilm. Litter was collected on an area of 345 cm^2, at nine points of each microenvironment, per plot. Litter was placed in paper bags and stored at room temperature. Soil samples were taken at 0–3 cm depth, after collecting the Biocrust or directly at the OA, in 15 points, per microenvironment; within each plot, 15 subsamples were mixed to form a composite sample, per each microenvironment, per plot, which were stored in black plastic bags, refrigerated at 10 °C, and transported to the laboratory.

2.3. Biocrusts species composition and cover

In laboratory, mosses, lichens and cyanobacteria were taxonomically identified [32]. Species richness for each biocrust was registered in terms of the observed species. A dissimilarity index by cluster analysis (Ward's method with Euclidean distances) for the species composition of mosses, lichens and cyanobacteria between microenvironments (Biocrusts-RI and Biocrusts-ORI) and seasons was used. This index is based on the presence-absence data, being equal to 0% under complete similarity, and 100% if there are not shared species [33]. Cover of the three main biotic components of the biocrusts (cyanobacteria, lichens and mosses) was determined using a 25 cm^2 square (5 cm × 5 cm), centered on each collected sample. This square was divided into a grid of 0.5 cm × 0.5 cm, and the cover of each biotic-crust component was evaluated by the point sampling method [13].

2.4. Litter mass

Litter samples were passed through two sieves (2 mm and 1 mm) to eliminate sand, carcasses and soil aggregates; litter in fresh weight was registered. Samples were oven-dried at 70 °C to constant weight to estimate dry mass. To include the fine litter that is mixed with soil, a litter sub-sample was ground to 450 μm and combusted at 600 °C/4 h in a muffle to estimate dry mass of litter soil free.