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Spectral monitoring of a system for the rehabilitation of burned soils based on inoculation with cyanobacteria and microalgae

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Keywords

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Abstract

Inocula containing photosynthetic microorganisms such as cyanobacteria and microalgae can promote the formation of biocrusts, improving the soil properties and allowing ecosystem recovery. The GreenRehab project aims to develop a low-cost, eco-friendly, and easy-to-implement system to rehabilitate burned soils and protocols to evaluate the success of an ecosystem after-fire recovery. For this purpose, native cyanobacteria and microalgae were isolated from soil/biocrusts and tested, with selected strains being cultivated on a large scale. To evaluate the performance of the proposed rehabilitation system (based on the inoculation of native cyanobacteria and microalgae), we analyzed spectral data scanned from a portable visible/near-infrared spectrometer that indirectly estimates top-soil photosynthetic activity. Several spectral indices based on the normalized difference combination of spectral bands were calculated and compared for their ability to assess photosynthetic activity over time. Results showed that treatments with microalgae and cyanobacteria effectively enhanced photosynthetic activity, with Trichocoleus stimulating soil rehabilitation the most. Moreover, the best performing normalized difference index was the one combining the 660 nm and 860 nm wavelengths. Parallelly, very-high resolution imagery obtained from a UAV equipped with a multispectral camera is currently being tested to assess the performance of different inocula previously selected from microcosm experiments in environmental conditions closer to real ones in post-fire scenarios. Preliminary results led us to develop an integrated protocol for image acquisition, radiometric calibration and photogrammetric post-processing. This allowed us to characterize baseline conditions in the test area, including geomorphology, vegetation and portray fine-scale patterns in greenness and photosynthetic activity. Overall, spectral measurements from portable spectrometers and UAVs open the possibility of assessing which treatments exploited in the GreenRehab project effectively enhance soil rehabilitation and recovery from frequent fires. Such innovation may translate into other "real-world" applications in ecology, forestry, and agronomy.

1. Introduction and context

The GreenRehab project aims to develop a system for rehabilitating burned soils by applying inocula composed of native and locally-harvested cyanobacteria and microalgae. These photosynthetic microorganisms promote

the formation of biocrusts improving the soil properties and allowing the re-establishment of the ecosystem (Rossi et al. (2012), Colina et al. (2014), Büdel et al. (2016), Lababpour et al. (2016)). For this purpose, native cyanobacteria and microalgae were isolated from soil/biocrusts and tested in microcosm experiments to select soil conditioners and plant growth enhancers. Selected strains will be cultivated on a large scale, and different microbial consortia and distinct dispersion methods will be tested in restricted burned areas. Finally, the soil properties, microbial community, edaphic fauna and vegetation recovery will be assessed before and after re-inoculation. By the end of the project, we intend to have a low-cost, eco-friendly, and easy-to-implement system to rehabilitate burned soils and a protocol to evaluate the success of an ecosystem after-fire recovery.

2. Approach

(I) A microcosm experiment was developed to select which native cyanobacteria and algae performed best for enhancing soil activity. This experiment was divided into controls (soil not inoculated) and four different inoculation treatments with soil, perlite and photosynthetic organisms isolated from biological soil crusts – one microalga: *Klebsormidium*; and three cyanobacteria: *Oscillatoria*, *Trichocoleus* and, *Nodosilinea*.

We evaluated the implementation and performance of rehabilitation of these treatments by analyzing the spectral data scanned from a portable visible/near-infrared (VNIR) spectrometer (LinkSquare-1, URL: https://linksquare.io, hereafter LS1, covering the VNIR region from 350 nm to 1100 nm) that indirectly estimates the top-soil photosynthetic activity.

Several spectral indices based on the normalized difference combination of spectral bands were calculated and compared in R statistical software (R Core-Team, 2019) for their ability to assess photosynthetic activity over time. Measures were collected weekly and systematically based on a predefined mesh placed over each soil tray. Ten spectral measurements per tray were collected weekly using LS1 handheld spectrometer.

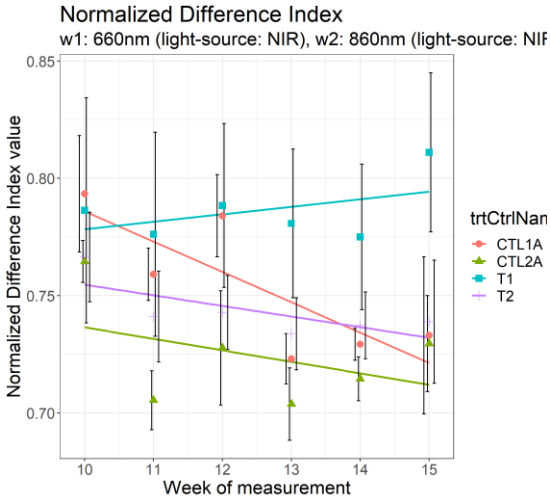
(II) Mesocosm experiments are also being performed in GreenRehab to assess the effectiveness of each cyanobacteria and microalgae inocula in environmental conditions closer to real ones found in post-fire scenarios. This effort involves developing a detailed framework to support post-fire severity and recovery monitoring (e.g., Torres et al. 2017), characterizing baseline conditions in the field site selected for the in-situ, and designing a tailored experimental setup (e.g., Gonçalves et al., 2016). In particular, very-high resolution imagery obtained from an unoccupied aerial vehicle (UAV, DJI Phantom-4) equipped with a multispectral camera (Parrot Sequoia+) is being tested to assess the performance of different inocula previously selected from microcosm experiments. Predefined semi-automated flights were used to collect images from the study area and later used for 3D photogrammetric assembly. Ground control points were collected with a centimetre-precision GNSS station to improve the accuracy of 3D reconstructions using Agisoft Metashape Pro software (Agisoft, 2021). Radiometric corrections were applied for multispectral VNIR images. A dense point cloud, orthomosaic, digital surface model (DSM) and spectral indices were obtained to characterize reference conditions.

3. Preliminary results

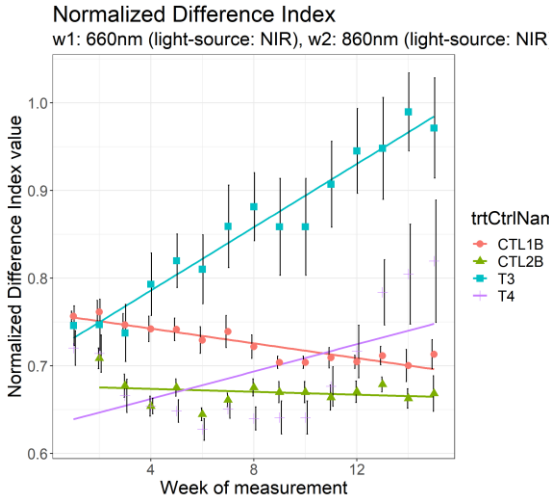
3.1. Microcosm experiments – hyperspectral monitoring

The results showed that the portable spectrometer LinkSquare-1 could provide reliable and relevant information for detecting VNIR spectral data. Treatments with microalgae and cyanobacteria effectively enhanced photosynthetic activity. When comparing the different treatments and their performances with spectral indices, *Trichocoleus* (T3) seemed to stimulate soil rehabilitation the most. Although *Nodosilinea* (T4) and *Klebsormidium* (T1) treatments showed an inferior performance to *Trichocoleus*, they still increased over time. *Oscillatoria* (T2) obtained the lowest results in stimulating top-soil photosynthetic activity based on spectral data. The best performing normalized difference index was the one combining the 660 nm (red) and 860 nm (NIR) using the infrared light source of the LS1 device.

(a)



(b)



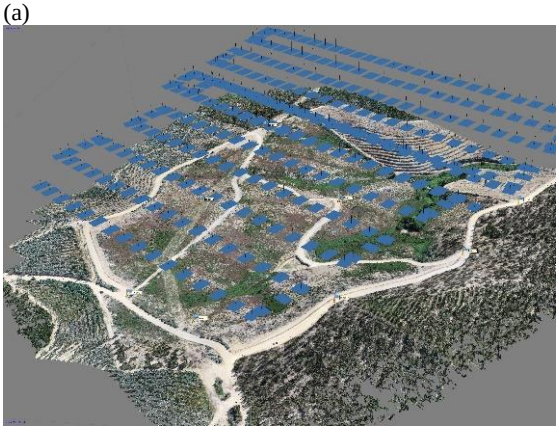
(c)

Figure 1 – Growth of the different microorganisms on the microcosm experiment monitored using a handheld LinkSquare-1 spectrometer for the collection of hyperspectral measurements for treatments (T): (a) T1 – Klebsormidium (microalga) and T2 – Oscillatoria (cyanobacterium); (b) T3 – Trichocoleus and T4 – Nodosilinea (cyanobacteria). CTL1A/CTL1B – burned soil moistened with BG11 medium; CTL2A/CTL2B – burned soil covered with perlite soaked in BG11 medium. (c) Spectral data collected with LS1 handheld spectrometer using a mesh over the soil surface.

3.2. Mesocosm experiments – UAV multispectral monitoring

Results from GreenRehab project have allowed us to devise a conceptual and analytical framework for fire severity assessment and post-fire recovery monitoring based on remote Earth observations (Marcos et al. 2021). Furthermore, field tests with the UAV/multispectral imagery have allowed us to detail the protocol for image acquisition, radiometric calibration and photogrammetric post-processing. Initial results point out that UAV imagery and DSM can be used to characterize baseline conditions in the test area, contributing to understanding geomorphology and vegetation patterns as well as dominant plant species (Fig.2 a–c). In addition, Normalized Difference Indices based on radiometrically calibrated images (Fig.2 d) can portray fine-scale patterns in greenness and photosynthetic activity.

(a)



(b)

(c) (d)

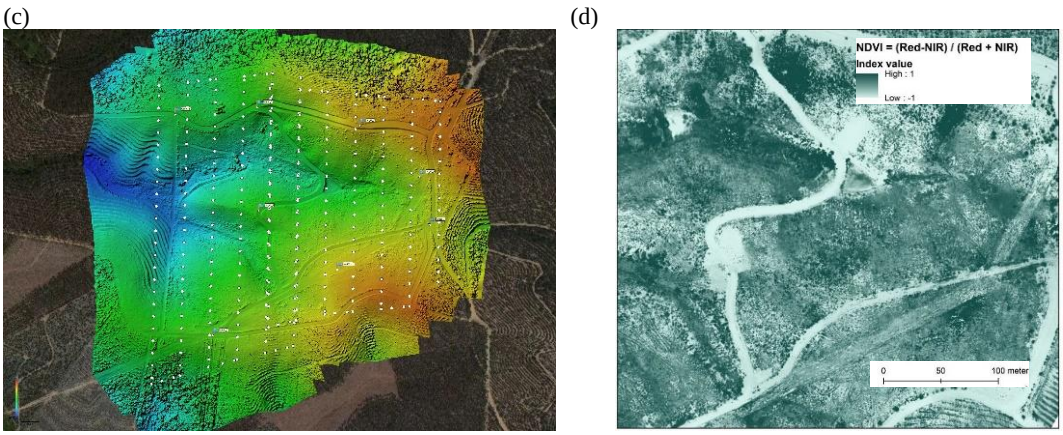


Figure 2 – Outputs from UAV surveys obtained for monitoring the macrocosm experiments in the field: (a) densified point-cloud, (b) orthomosaics with ultra-high resolution (2.5 cm), (c) digital surface model (blue and 'colder' colors indicate lower altitudes whereas reds and warmer ones indicate higher elevations), and (d) image depicting the normalized difference vegetation index (calculate from red and near-infrared spectral bands). Darker greens show higher amounts of vegetation in the test/experimental site.

4. Final remarks and future research

Spectral measurements and indices from portable spectrometers and UAVs open the possibility of assessing which treatments exploited in GreenRehab project enhance soil rehabilitation and recovery from frequent fires. Such innovation may translate into other "real-world" applications in ecology, forestry, and agronomy.

Future research will continue to expand these results and explore how image time series, collected at regular time steps, can aid in monitoring the effectiveness and velocity of different treatments to provide a low-cost and easy-to-implement system to rehabilitate burned soils.

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