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Spectra and vegetation index variations in moss soil crust in different seasons, and in wet and dry conditions

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ABSTRACT

Similar to vascular plants, non-vascular plant mosses have different periods of seasonal growth. There has been little research on the spectral variations of moss soil crust (MSC) over different growth periods. Few studies have paid attention to the difference in spectral characteristics between wet MSC that is photosynthesizing and dry MSC in suspended metabolism. The dissimilarity of MSC spectra in wet and dry conditions during different seasons needs further investigation. In this study, the spectral reflectance of wet MSC, dry MSC and the dominant vascular plant (*Artemisia*) were characterized in situ during the summer (July) and autumn (September). The variations in the normalized difference vegetation index (NDVI), biological soil crust index (BSCI) and CI (crust index) in different seasons and under different soil moisture conditions were also analyzed. It was found that (1) the spectral characteristics of both wet and dry MSCs varied seasonally; (2) the spectral features of wet MSC appear similar to those of the vascular plant, *Artemisia*, whether in summer or autumn; (3) both in summer and in autumn, much higher NDVI values were acquired for wet than for dry MSC (0.6 ∼ 0.7 vs. 0.3 ∼ 0.4 units), which may lead to misinterpretation of vegetation dynamics in the presence of MSC and with the variations in rainfall occurring in arid and semi-arid zones; and (4) the BSCI and CI values of wet MSC were close to that of *Artemisia* in both summer and autumn, indicating that BSCI and CI could barely differentiate between the wet MSC and *Artemisia*.

1. Introduction

Biological soil crusts (BSCs), formed by different combinations of microphytic communities including mosses, lichens, liverworts, algae, fungi, and cyanobacteria, are widely distributed on the land surface, particularly in arid, semi-arid, alpine, polar, and other ecologically fragile regions (Belnap, 2001; Beringer et al., 2001; Fang et al., 2008; Smith and Walton, 1985). Moss soil crust (MSC), mainly consisting of mosses, is one type of widespread BSC in arid and semi-arid areas and covers more than 10% of the land surface in some semi-arid areas in China (Fang and Zhang, 2011). These play an important role in the desert ecosystem, including increasing C- and N-sinks, the water-holding capacity of soils, and stabilizing soils against wind and water erosion (Belnap, 2001; Belnap, 2002; Beringer et al., 2001; Lange et al., 1992; Solheim et al., 2006; Verrecchia et al., 1995).

To investigate the coverage of BSCs, remote sensing images were used in early research studies to aid mapping (Chen et al., 2005; Karnieli, 1997; Karnieli et al., 1999; Karnieli and Sarafis, 1996; Oneill, 1994; Rodríguez-Caballero et al., 2014; Ustin et al., 2009; Weber et al., 2008; Wessels and van Vuuren, 1986). The spectral characteristics of BSCs were studied in more detail, and it was found that higher reflectivity in the blue region is caused by the spectral characteristics of the phycobilins in BSCs (Karnieli and Sarafis, 1996). According to this study, the authors designed a spectral crust index (CI), in which BLUE, RED and NIR of the 400–500, 600–700, and 700–800 nm spectral bands were used (Karnieli, 1997). For mapping lichen-dominated BSCs, another biological soil crust index (BSCI) was proposed that used the reflectance of the green and red bands (corresponding to bands 2 and 3 for the Landsat ETM+ sensor) (Chen et al., 2005). To make use of the hyperspectral dataset, an approach using a continuum removal crust identification algorithm (CRCIA) was established (Weber et al., 2008). Using

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multispectral remote sensing thermal images, a new spectral index was created for the discrimination of sand and BSCs of different types (Rozenstein and Karnieli, 2014). Most of the previous research focused on the spectral characteristics of cyanobacterial and lichen-dominant soil crusts, although Karnieli and Sarafis paid attention to the spectral differences among five different lichen-dominant soil crusts that had a certain number of individual counts of moss (Karnieli and Sarafis, 1996). Compared with cyanobacteria and lichen, mosses have much more chlorophyll and a higher photosynthetic capacity, similar to vascular plants (Pojar and Mackinnon, 1994). Further investigation is needed to determine whether the spectra of MSCs are similar to those of vascular plants or different from those of other types of BSCs.

Botanically, mosses are one group within the bryophytes, and they are non-vascular plants. However, similar to vascular plants, they have chlorophyll and can harvest sunlight to create food through photosynthesis (Pojar and Mackinnon, 1994). It is easy to dismiss mosses as 'lower' plants because they were the earliest plants to evolve, but they can resume photosynthesizing and growing similar to vascular plants when water is available and suspend metabolism when it is not. When an MSC is wet, it turns green and net photosynthesis returns to a substantially normal rate within approximately 30 ~ 45 min of remoistening (Proctor, 2000). Lacking a vascular system, mosses have a long-lived gametophyte-dominant growth period and a short-lived sporophyte-dominant growth period (Reski, 1998), and they change their chlorophyll contents seasonally (Kershaw and Webber, 1986). The spectral characteristics of most vascular plants are dissimilar in different seasons or growth periods. This raises the question of whether the spectra in the sporophyte and gametophyte-dominant growth periods are uniform. Although some research has studied the spectral reflectance characteristics of BSCs in more detail (Chen et al., 2005; Karnieli, 1997; Karnieli et al., 1999; Karnieli and Sarafis, 1996; Oneill, 1994; Rodríguez-Caballero et al., 2014; Weber et al., 2008), little research has involved sampling the spectral features of BSCs according to different phenologies or growth periods.

Previous research suggested that some coverage of mosses in BSCs in wet conditions could have increased the normalized difference vegetation index (NDVI) by 0.19 units over that under dry conditions (Karnieli and Sarafis, 1996). Other research showed that 100% coverage of wet MSCs resulted in a much higher NDVI value (0.657) than the dry MSC NDVI value (0.320) (Fang and Zhang, 2011). Although the effects of soil surface moisture on the NDVI of MSCs have been analyzed, few researchers have shown an interest in the variations in the vegetation index of MSCs with seasonal changes. Based on the above findings, the CI (Karnieli, 1997) and BSCI (Chen et al., 2005) were proposed for investigating the coverage of BSCs. However, the applicability of the two indexes for MSCs requires further testing because mosses have chlorophyll similar to vascular plants.

In this study, we investigated the spectral characteristics and their variations of MSCs and *Artemisia* (a local dominant vascular plant) in summer (July) and in autumn (September) and under wet and dry conditions after in situ measurements of spectral reflectance and soil moisture. We also compared the variations in the NDVI, BSCI and CI of MSCs and *Artemisia* in different seasons and under different soil moisture conditions.

2. Material and methods

2.1. Study site

This study was conducted in July and September 2006 on sites near the National Research Station for Ordos Grassland Ecosystem (39°29′N, 110°11′E, 1300 m above sea level) in Ordos in the Inner Mongolia autonomous region of China. The annual mean precipitation is ~358 mm, of which 60–80% falls between June and August. The average annual temperature is 5.7 °C, and the monthly mean temperature is 22 °C in July and −10 °C in January (Fang and Zhang, 2013). Much of the region is covered by loose sands and BSCs. *Artemisia ordosica Krasch* is the dominant and the most widespread vegetation, covering more than 10% of all habitats. Fixed, semi-fixed, and shifting sand dunes are the three typical landscapes on the Ordos Plateau.

2.2. Measurement of MSC coverage and selection of plots

A total of 22 high-MSC-coverage plots without any non-vascular plants were chosen to investigate MSC coverage near the Ordos Sandland Ecological Research Station. All cover values for each plot were measured using a vegetation measurement frame, which was a 1.00 × 1.00 m quadrat partitioned into a grid of 100 10 × 10 cm squares, where the percentage of cover was measured using the average cover values for all of the 10-cm squares (Elzinga et al., 2001). Five plots that had more than 90% coverage by MSCs were selected as permanent plots for further investigation into the characteristics and field spectrum measurements.

2.3. Wet and dry MSC plots

Wet MSC plots that had more than 20% water and dry MSC plots that had less than 5% water were defined for the soil moisture conditions. For each date, the spectral profiles were collected from all five selected plots where, as previously stated, the coverage of the MSC was more than 90%.

2.4. Observations of MSC growth periods and characteristics

From July to September, the gametophyte-dominant or sporophyte-dominant growth periods were observed using a magnifying glass to count the individual sporophytes developed in each permanent plot and to estimate the development every 10 days on the five permanent plots. A sporophyte-dominant growth period is defined as a period when more than 80% of individual sporophytes develop in all five permanent plots, and a gametophyte-dominant growth period is defined as a period when less than 20% of individual sporophytes develop. July was a period of gametophyte-dominant growth when no sporophytes were found. September was a period of sporophyte-dominant growth when more than 98% of individual sporophytes developed. To avoid affecting spectral sampling, a topmost 2-cm MSC section with a 50-mm diameter in the corner of each permanent plot was sampled in the field using a medium-sized aluminum soil sample container; this sample was carried carefully to the laboratory for analysis. In the laboratory, three 10-mm-diameter MSCs were obtained by resampling using a glass test tube. One of the 10-mm-diameter MSCs was used to identify moss species in the Herbarium, Institute of Botany, Chinese Academy of Sciences. Another was used to measure bulk density using the paraffin-coated clod method (McKenzie et al., 2002). A third had its thickness measured using vernier calipers at 0.1 mm and was then used to count individual mosses.

2.5. Field spectra sampling and processing

2.5.1. Multispectral radiometer – Cropscan

The spectral profiles of MSCs were collected using a Cropscan MSR16R passive multispectral radiometer (CROPSCAN, Inc., Rochester, NY, USA). This spectrometer consisted of upward and downward facing radiation transducers with 16 fixed wavebands (the waveband centers were 460, 510, 560, 610, 660, 680, 710,760, 810, 870, 950, 1100, 1220, 1480, 1500 and 1650 nm; the bandwidth