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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

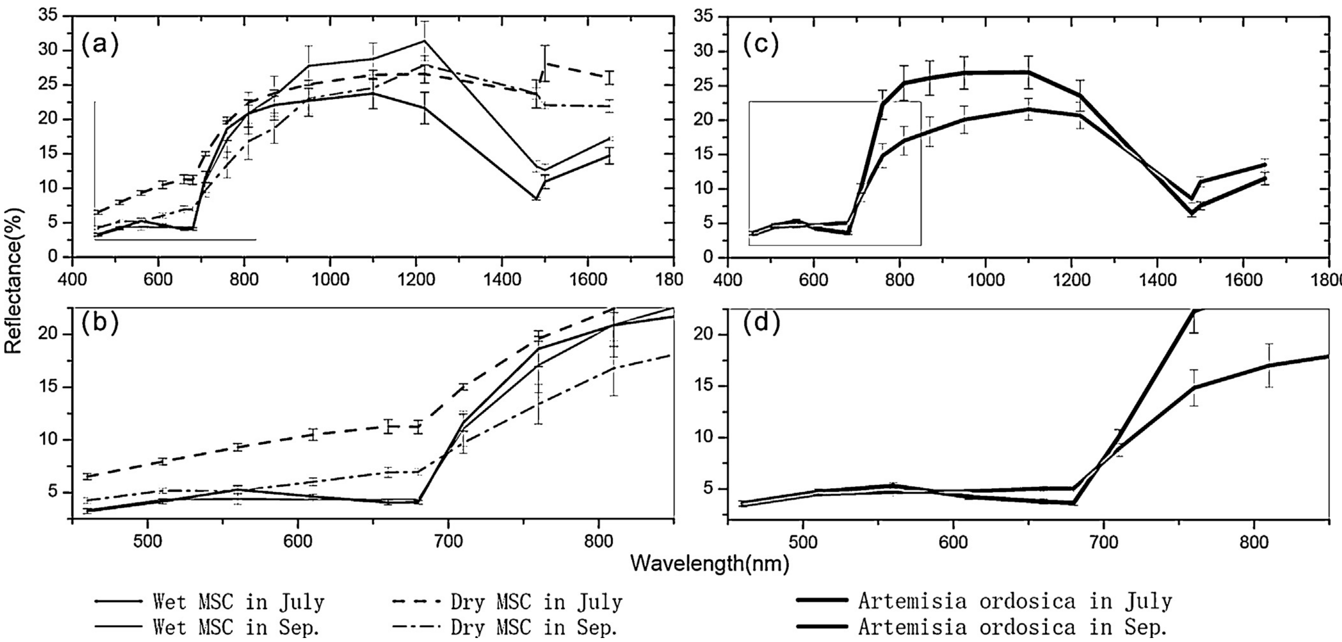

Fig. 1. Spectra of wet MSC, dry MSC and *A. ordosica* in July and September.

of the 15 filters ranged from 8.1 to 13.5 nm for the 460–1500 nm wavebands, and the 195 nm bandwidth for the 1650 nm waveband) with a 28° field of view. The diameter of the field of view was half the height of the radiometer above the canopy [http://www.cropscan.com/msr.html (September 2012)].

2.5.2. Field spectral sampling

The field spectral measurements consisted of five plots each of MSC and *A. ordosica*, which was the dominant and most widespread dwarf shrub in the research region. Five plots with MSC coverage of more than 90% were used to obtain the spectral profiles of MSC using the Cropscan MSR16R in July and October, 2006. Each month, 15 field spectral samplings were carried out under different moisture conditions (rainfall or simulated rainfall and intensive evapotranspiration of the local semi-drought continental climate ensured different moisture conditions for the MSC during a month). At each sampling time, the MSC in combination with soil of 1.0–1.2 cm depth in the soil profile were sampled randomly to determine the moisture content using an oven-drying method. Five plots of the dominant species of dwarf shrub, *A. ordosica* (coverage of 100%), were sampled to obtain spectra at the same time. The spectral reflectance was measured in the field from 10:00 to 15:00 h under clear weather conditions using the Cropscan multispectral radiometer. The spectrometer sensor was held 1.5 m above the canopy of the plant or the surface of the MSC, and the diameter of the spectrally measured plot was 75 cm. The spectral reflectance of each plot in each period was sampled to obtain five individual spectra characterizing each of the site-specific spectral varieties. Before each time of spectral measurements, the Cropscan was calibrated using the white calibration plate by following the calibration methodology available in the device manual (http://www.cropscan.com/2ptupdn.html).

2.6. Processing of field spectra

The mean and standard error of MSC spectral reflectance at each sampling time was calculated in Excel 2003 using the mean of the five individual spectra. The spectra of the MSCs were calculated using Excel 2003 from five plots at each sampling date in July and September. The spectra of wet and dry MSCs in July and September were obtained on three or four of the dates (wet MSC plots that had more 20% water and dry MSC plots that had less than 5% water). The spectra of *A. ordosica* were analyzed using Excel 2003 for the mean and standard errors from the mean of five dates (mean on each date from the mean of five plots) in July and September. The statistics in this study were calculated using SPSS 17.0 (SPSS Inc., Chicago, IL, USA)

3. Results and discussion

3.1. Characteristics of MSC

Compared with the Sede Hallamish dune field (along the Israel/Egypt political border) that is mostly covered by cyanobacteria (Karnieli et al., 1999), our study site is mainly covered by mosses. The dominant moss species of MSCs in the research area was *Bryum argenteum* Hedw. (Table 1). The moss density, given as individual counts per square meter, was $2.44 \times 10^6\ m^{-2}$. The density of the moss was three times the value reported by Karnieli et al. (1999) for the Sede Hallamish dune field, where the highest density was $7.8 \times 10^5\ m^{-2}$ (Karnieli et al., 1999). Because of the chlorophyll in the moss and their photosynthetic activity, the NDVI in the Sede Hallamish dune field could vary from 0.10 to 0.29 and increase by approximately 0.20 units when the dry MSC was moistened (Karnieli et al., 1999). The higher density of wet moss could result in a higher NDVI value, which could reach up to 0.65 (Fang and Zhang, 2011). In this study, the variation in the spectra and vegetation indexes of wet MSCs in contrast to dry MSCs was further analyzed.

Table 1
Characteristics of moss soil crust.

Characteristics of MSC	Value or attribute
Species	*Bryum argenteum* Hedw.
Thickness (cm)	0.9 ± 0.2[a]
Bulk density ($g\,cm^{-3}$)	1.82 ± 0.13
Individual counts (m^{-2})	$(2.44 \pm 0.26) \times 10^6$
Percentage of sporophytes in July	None
Percentage of sporophytes in September	94.1 ± 4.2%

[a] Mean ± standard deviation, $n = 10$.

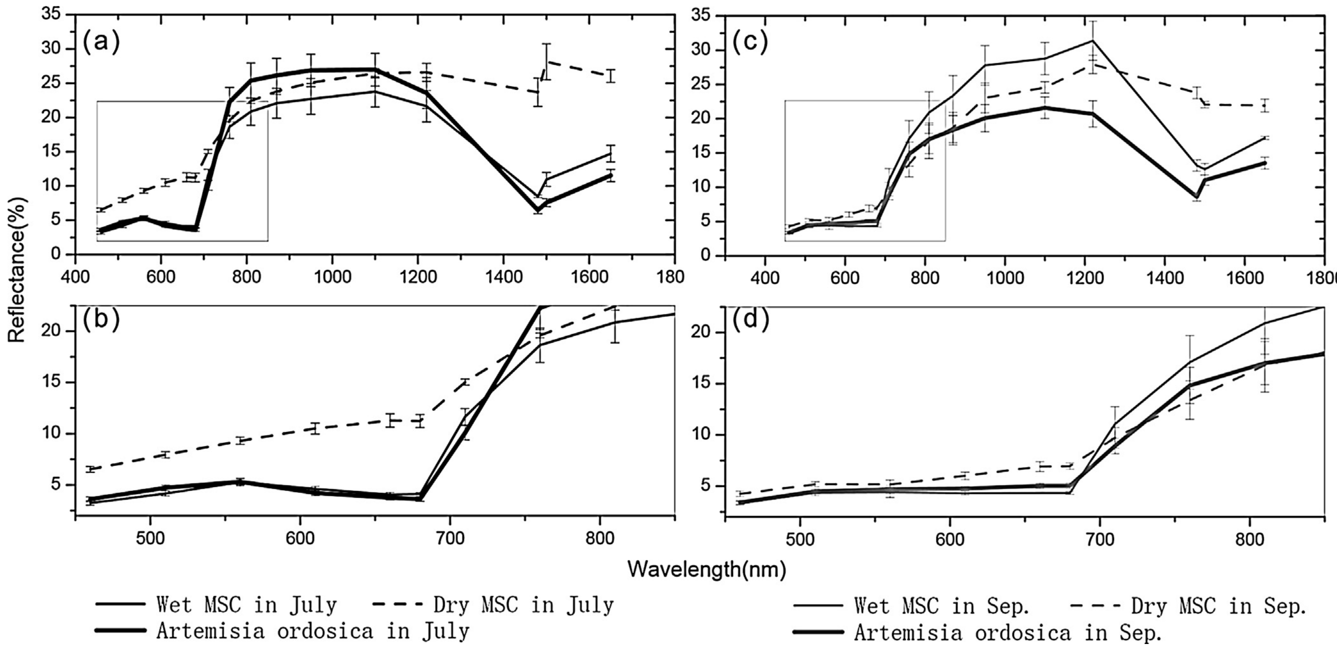

Fig. 2. Spectra of *A. ordosica* in contrast to wet MSC and dry MSC in July and September.

3.2. Spectral characteristics of MSC and A. ordosica

The variation in spectral reflectance between sampling points for MSC and *A. ordosica* in different seasons or moisture conditions is shown with standard deviation bars (Fig. 1). The wet MSC's spectral reflectance in July was dissimilar to the dry MSC's spectral reflectance in September (Fig. 1(a)). Compared with the wet MSC in July, the wet MSC in September had a higher reflectance of between 950 and 1650 nm (950, 1100, 1220, 1480, 1500 and 1650 nm), a lower reflectance at 560 nm and similar spectral features in other wavebands (460, 510, 610, 660, 680, 710,760, 810 and 870 nm). The spectral behaviors of dry MSC in September had a lower reflectance for the 460 ~ 1100 nm wavebands (460, 510, 560, 610, 660, 680, 710, 760, 810, 870, 950 and 1100) and a higher reflectance for the 1500 and 1650 nm wavebands than those of the dry MSC in July. The dissimilarity of MSC spectra in different seasons could be explained by the mosses having a long-lived gametophyte-dominant growth period and a short-lived sporophyte-dominant growth period. In the field investigation, using a magnifying glass, we found that sporophytes had completely developed in September, but few appeared in July. This indicated that MSC spectra varied with different growth periods.

A. ordosica is a vascular plant whose spectral reflectance showed a typical response to green vegetation across the 16 wavebands (Fig. 1(b)). Reflectance was the lowest in the visible range (460, 510, 560, 610, 660, 680 and 710 nm wavebands), with a peak at 560 nm, which was reported previously in several studies (Maas, 1998; Tucker and Miller, 1977). Unlike the spectra in September, the spectral reflectance of *A. ordosica* in July had higher values between 760 and 1220 (760, 810, 870, 950, 1100 and 1220 nm wavebands), had a higher reflectance peak at 560 nm, and had lower values at 610, 660, 680, 1480, 1500 and 1650 nm than those in September. The trend in reflectance from canopies was because of the leaf pigments (such as chlorophyll) that strongly absorb irradiance in the visible wavebands, resulting in relatively low visible reflectance. In July, *A. ordosica* was in a fast-growing period that had the strongest photosynthesis (Li et al., 1998). Because September is close to the end of the growing season for *A. ordosica*, the characteristics of spectra in the senescence phase had gaps compared with typical green vegetation in most of the wavebands.

3.3. Spectra of MSC compared with A. ordosica

The spectra of wet and dry MSC in contrast to *A. ordosica* are shown in Fig. 2, indicating that the spectral reflectance curve of the wet MSC was similar to those of vascular plants in July and September. In July (Fig. 2(a)), the spectral reflectance for wet MSC showed typical spectra similar to green vegetation across the 16 wavebands, with a peak at 560 nm, and had the same spectral reflectance curve between 460 and 710 nm as vascular plants. This occurred even though the reflectance in the 760, 810, 870, 950, 1100 and 1220 nm wavebands had lower values and that in the 1480, 1500 and 1650 nm wavebands had higher values than *A. ordosica*. Additionally, in contrast to *A. ordosica*, the spectral reflectance for wet MSC in September had higher values in the 760, 810, 870, 950, 1100, and 1220 nm wavebands. Similar to the results in July, the spectral reflectance for wet MSC in September also had higher values at 1480, 1500 and 1650 nm (Fig. 2(b)). Karnieli and Sarafis (1996) showed that when the biogenic crust (moss) was wet, its spectral reflectance had much higher values overall than vascular plants, although its curve had a relatively small peak in the green region (Karnieli and Sarafis, 1996). In contrast with the findings of Karnieli and Sarafis (1996), the spectral reflectance curve of MSCs in our research almost overlaps that of *A. ordosica* and yields a typical vegetation spectral reflectance curve in July and September: it dips in the blue and red regions, has relatively small peaks in the green regions and has high reflectance in the near infra-red (NIR). The similarity in spectra between wet MSCs and vascular plants could be a function of the chlorophyll in the leaves and the return of net photosynthesis to a normal rate when the MSC was remoistened (Proctor, 2000). In contrast to previous research that only measured spectra in some growth periods of moss, we found differences in the MSC spectral reflectance in different growth periods of moss that could be associated with seasonal changes in the chlorophyll content in the moss (Kershaw and Webber, 1986).

3.4. Vegetation indexes of wet MSC and dry MSC

When remoistened, MSC turns green and a notable change in the reflectance curve occurs. The spectral reflectance curve of the wet MSC is similar to those of the vascular plants and therefore, may

Table 2
Vegetation indexes.

Normalized difference Vegetation index (NDVI)	$(R_{810} - R_{660})/(R_{810} + R_{660})$
Crust index (CI) (Karnie li, 1997)	$1 - (R_{600\sim700} - R_{400\sim500})/(R_{600\sim700} + R_{400\sim500})$[a]
Biological soil crust index (BSCI)(Chen et al., 2005)	$(1 - L\|R_{600\sim700} - R_{500\sim600}\|)/R_{500\sim950}$ $(L = 2)$[a]

[a] *Note*: $R_{600\sim700}$ averaged by reflectance in 610, 660, and 680 nm; $R_{400\sim500}$ averaged by reflectance in 460 and 510 nm; $R_{500\sim600}$ averaged by reflectance in 560 and 610 nm; $R_{500\sim950}$ averaged by reflectance in 510, 560, 610, 660, 680, 710, 760, 810, 870 and 950 nm.

lead to changes in the vegetation indexes (VIs). As the most widely used VI, NDVI was employed to test their variation (Table 2). The CI (Karnieli, 1997) and BSCI (Chen et al., 2005) were also needed to test whether they could be applied to identify MSCs among local vascular plants because mosses have chlorophyll similar to vascular plants (Table 2).

The changes between wet and dry MSCs compared with *A. ordosica* in July and September are shown in Table 3. Different types of VIs (NDVI, CI and BSCI) had much higher values for wet MSC than for dry MSC, whether in July or in September. In July, the values of wet vs. dry MSCs for NDVI, CI and BSCI were, respectively, 0.66 vs. 0.33, 0.92 vs. 0.79, and 0.94 vs. 0.70. In September, the values of wet vs. dry MSCs for NDVI, CI and BSCI were, respectively, 0.65 vs. 0.41, 0.94 vs. 0.83, and 0.96 vs. 0.74.

Although the reflectance values were different in July and September, the NDVI values of wet MSCs in this study reached 0.66 (July) and 0.65 (September) and were significantly greater than the previously reported value of 0.29 by Karnieli et al. (1999). This difference could be because the density of moss in our research $((2.44 \pm 0.26) \times 10^6$, Table 1) was much higher than that in the plots of Karnieli and Sarafis (1996) (7.8×10^5). This indicates that higher densities of moss could have a higher vegetation index. Karnieli et al. (1999) and Karnieli and Sarafis (1996) suggested that the lichen-dominant soil crust (which had some individual mosses) under wet conditions had an increase of 0.19 for the NDVI value over dry conditions (Karnieli et al., 1999; Karnieli and Sarafis, 1996). However, Fang and Zhang (2011) showed that 100% coverage of wet MSC has a much higher NDVI value (0.657) than the dry MSC NDVI value (0.320). In this research, NDVI increased to 0.33 in July and 0.24 in September. This finding indicated that the increase in the NDVI value of MSCs after wetting could vary in different seasons.

In the study area, MSC, which had an average coverage of 12.25% (Fang and Zhang, 2011), would have made a considerable contribution to the composition of the vegetation index. The coverage of moss and lichen was 5.6 ~ 21.5% in another area of north China (Xu et al., 2003) and 24.5% in the Mojave Desert, CA, USA (Thompson et al., 2005). The MSC could only make use of water in the topsoil (Pojar and Mackinnon, 1994). Because of the high coverage of MSC in arid and semiarid areas, the NDVI could be much higher after rainfall because of the recovery photosynthesis of moss during the growth period. This would result in instability of NDVI in the region because of the rapidly changing moisture in the topsoil. A natural vegetation phenology assessment by NDVI yielded a similar result, which suggested that biological soil crusts show the earliest and highest weighted NDVI peak during the rainy season (Karnieli, 2003). The vegetation index, as the most important parameter of terrestrial ecosystems, was widely used to monitor regional and global plant growth, plant phenology, land use and land cover, biomass and vegetation productivity (Horion et al., 2013; Johansen and Tømmervik, 2014; Myneni et al., 1997; Shen et al., 2014; Thayn, 2012). However, the biomass and vegetation productivity of MSCs was much less than that for vascular plants. The "maximum value composite" (MVC) technique was used to eliminate the effect of clouds and haze for the vegetation maps (Holben, 1986). Misinterpretation of the vegetation dynamics could be more serious because of the MVC technique used in areas with high coverage of MSC to compose the global vegetation maps in the study of vegetation dynamics. Further research is needed to assess the roles of wet and dry MSCs in affecting the vegetation index of the MVC.

Table 3
Variation in vegetation indexes between wet and dry MSCs in contrast with *A. ordosica* in different seasons.

VIs in season	Plants	Mean	STDEV
NDVI	Wet MSC	0.66	0.03
in	Dry MSC	0.33	0.03
July	*Artemisia*	0.74	0.07
NDVI	Wet MSC	0.65	0.04
in	Dry MSC	0.41	0.03
September	*Artemisia*	0.52	0.03
BSCI	Wet MSC	0.94	0.03
in	Dry MSC	0.70	0.04
July	*Artemisia*	0.83	0.05
BSCI	Wet MSC	0.96	0.03
in	Dry MSC	0.74	0.02
September	*Artemisia*	0.93	0.04
CI	Wet MSC	0.92	0.02
in	Dry MSC	0.79	0.01
July	*Artemisia*	1.05	0.08
CI	Wet MSC	0.94	0.02
in	Dry MSC	0.83	0.01
September	*Artemisia*	0.89	0.02

3.5. Vegetation indexes in summer and autumn

As Table 3 shows, the BSCI of *Artemisia* varied from 0.83 in July to 0.93 in September, and the BSCIs of wet MSC were 0.94 in July and 0.96 in September. The BSCI (0.94) of wet MSC in July was very close to the BSCI (0.93) of *Artemisia* in September. The CI of *Artemisia* varied from 1.05 in July to 0.89 in September, and the CIs of wet MSC were 0.92 in July and 0.94 in September. The CI values (0.92, 0.94) of wet MSC were between the CI values of *Artemisia* (1.05, 0.89) in July and September. This indicated that BSCI and CI could barely differentiate between the wet MSC and *Artemisia*.

In July, the NDVI value of *Artemisia* was higher than that of wet MSC. In contrast, the NDVI value of *Artemisia* is lower than that of wet MSC in September. The seasonal changes in NDVI could be interpreted as the phenology of moss changing from a gametophyte-dominant growth period in July to a sporophyte-dominant growth period in September, and the phenology of *Artemisia* changing from a fast-growing period into the senescence phase, as previously discussed (Kershaw and Webber, 1986; Li et al., 1998).

4. Conclusions

The spectra of moss soil crust variations in two growth periods and variations under wet and dry conditions were characterized by the measurements of spectral reflectance and soil water in situ in the field. The variations in the vegetation indexes (NDVI, CI and BSCI) were also analyzed in different seasons and based on soil moisture. The spectral characteristics of wet MSCs were similar to those of vascular plants in the two seasons, especially for those that had the same spectral reflectance curve as the vascular plants between the 460 and 710 nm wavebands (460, 510, 560, 610, 660, 680, and 710 nm). The spectra of MSCs in the summer were dissimilar to those in autumn, indicating that the spectral characteristics of MSCs varied with the season. The higher density of individual moss samples in the MSCs may contribute to higher NDVI values. The spectral feature produces a much higher NDVI value for the wet MSC than for the dry MSC (0.60 ~ 0.70 vs. 0.30 ~ 0.40 units). The NDVI values of wet MSCs are approximately twice that of dry MSCs in summer and autumn. Because of the existence of MSCs and rainfall variations in arid and semi-arid zones, the high coverage of MSC may lead to misinterpretation of the vegetation dynamics and to overestimations of the productivity of the ecosystem. Regarding the similarities of the BSCI and CI values between wet MSC and *Artemisia*, the BSCI and CI could barely differentiate between the wet MSC and *Artemisia*.

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