SPECTRAL CHARACTERIZATION OF CHANGES IN GRASSLAND UNDER CLIMATIC AND SOIL GRADIENTS IN KOHALA, HAWAII

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1. INTRODUCTION

Kohala Mountain, in Northern Hawaii, provides an ecosystem characterized by a strong climatic gradient along the leeward side of the mountain. The climatic gradient extends from arid to humid conditions from the coast to the top of the mountain. Along this climatic gradient, soil biogeochemical processes operate differently. Chadwick et al. (2003) found that increasing rainfall with increasing elevation caused fundamental changes in soil physical and chemical properties. Vegetation, which is sensitive to water availability and soil characteristics for its development, should be a good indicator of climatic shifts that occur on Kohala Mountain.

Field-level hyperspectral data provide a rich data source to quantitatively and qualitatively characterize land surface features and can be used as a reference for airborne or satellite sensor data. Once water status of vegetation is estimated using hyperspectral data (Curran, 1989; Kumar et al., 2001), vegetation changes over Kohala Mountain can be well characterized by using remote sensing. We analyzed changes in grassland cover along Kohala Mountain, coupling grass field spectra with climate and soil data. The objectives of this study are 1) spectral characterization of grassland changes along climatic and soil gradients over Kohala Mountain, and 2) analysis of the relationships between environmental parameters (climate and soil) and field spectra.

2. STUDY SITE DESCRIPTION

Our study site is located on the leeward side of Kohala Mountain (20.4N, 155.4.30W). Eight transects were selected along the climatic gradient on the leeward side of Kohala Mountain (Figure 1). Elevations range between 186 m and 1138 m at the study site. Annual precipitation varies from 180 mm, at site B, to 1380 mm, at site J. There are basically four dominant vegetation species along the sample transects: Buffel grass (*Cenchrus cillaris*) and keawe tree (*Prosopis pallida*), mostly found in the dry areas, and kikuyu grass (*Pennisetum clandestinum*) and orchard grass (*Dactylis glomerata*) found from intermediate to higher elevation sites. Soils along the sampling transects were developed on the same parent material, Hawi lavaflow.

3. METHODS

There are three steps involved in this study: 1) calculation of climatic parameters, 2) soil sampling and spectral measurements in the field, and 3) data processing and analyses.

3.1 Calculation of climatic parameters

Monthly precipitation was calculated using a second-order polynomial developed by Chadwick et al. (2003). This equation was developed based on nearly 20 years of rainfall records measured at nine rainfall gauges in Kohala. Monthly potential evapotranspiration (PET) was interpolated from the PET map developed by Ekern and Chang (1985) and Shade (1995). Water

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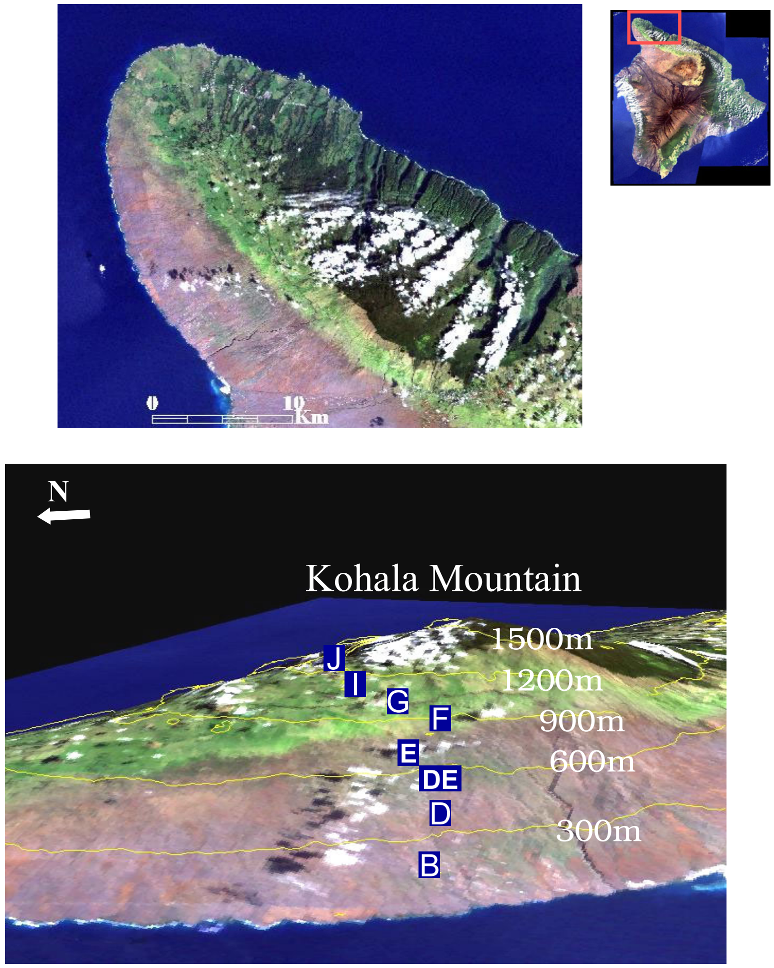

Figure 1. Overview of Kohala Mountain (above), Sample transects along the leeward side of Kohala Mountain

balance was calculated simply by subtracting Monthly PET from Monthly Precipitation. For more details, see Chadwick et al. (2003).

3.2 Soil sampling and spectral measurements in the field

The fieldwork was conducted from June 23 through July 2, 2002. We collected soil samples and field-spectra from each transect. Most transects were 50 m long, but for site F, which is a topographically rough land surface with variable vegetation types (mixed grass and shrub), we established a 100 m transect. An ASD full range spectrometer (350 to 2500 nm; Analytical Spectral Devices, Boulder, Colorado), borrowed from JPL/NASA, was used for field optical measurements over the transects. The ASD spectra were collected with a 22^{o} field-of-view (FOV) at 2-m intervals along each transect at a 1m sensor height. All measurements were collected within 2 hours of local solar noon on clear-sky days. Five replicates were measured for each grass canopy. These spectra were standardized to spectralon (Labsphere, Inc, North Sutton, NH) measured at approximately 10-minute intervals, and converted into reflectance. Following each spectral measurement, grass canopy height and digital photographs of the grass canopy were measured. Soil classification for each study transect had already been accomplished by Chadwick et al. (2003). For this study, six soil samples were collected from 0 to 30 cm from each transect for physical and chemical analyses.

3.3 Data analyses

Two vegetation indices were calculated from the ASD reflectance spectra: the Normalized Difference Vegetation Index (NDVI) = [NIR-R]/[NIR+R] (Choudhury, 1987) and the Soil Adjusted Vegetation Index (SAVI) = 1.5*([NIR – R]/[NIR+R+0.5) (Huete, 1988). Linear spectral mixture analysis (Adams et al., 1993) was also performed to decompose the ASD spectra into four fractional components: non-photosynthetic vegetation (NPV), green vegetation (GV), soil, and shade. Additionally, root-mean-square (RMS) error was calculated for each measurement. Endmembers were selected by comparing our spectral library to the corresponding canopy digital photographs taken from the same field spectral measurement points.

Soil physical and chemical analyses were conducted in the laboratory. In this study, soil chemical data were not used. Soil physical properties used in this study were: Coarse fragment % and pore volume. More details regarding the laboratory analyses, see Chadwick et al. (2003).

4. RESULTS AND DISCUSSION

4.1 Water balance and grassland changes derived from hyperspectral data

Figure 2 shows water balances at different sites, obtained in February, April, June, and December. We divided the transects into three zones: dry, intermediate, and wet. In the dry zone (B, D, and DE), water balance is always negative from December to June, while the wet zone (I and J) shows positive water balance from December to April, and negative in June.

The spectral reflectances in Figure 3 are related to the land surface characteristics of each transect and changes in grassland over the climatic gradient. Low and flat reflectance spectra in the dry zone indicate the presence of bare soil and low vegetation coverage. Dry grass is well expressed by the ligno-cellulose absorptions in the short wave-infrared (2100 to 2300 nm). The intermediate zone shows the transition of spectral signatures from dry grass to green grass, with an increase of chlorophyll absorption in the visible region. In the wet zone spectra, the reflectances show the characteristics of green vegetation such as more pronounced chlorophyll absorption in the visible, a pronounced red-edge, and the water absorption features found at the 970 nm, 1200 nm and 1450 nm in the near infrared (Curran, 1989; Dawson et al., 1992; Peñuelas et al., 1993).

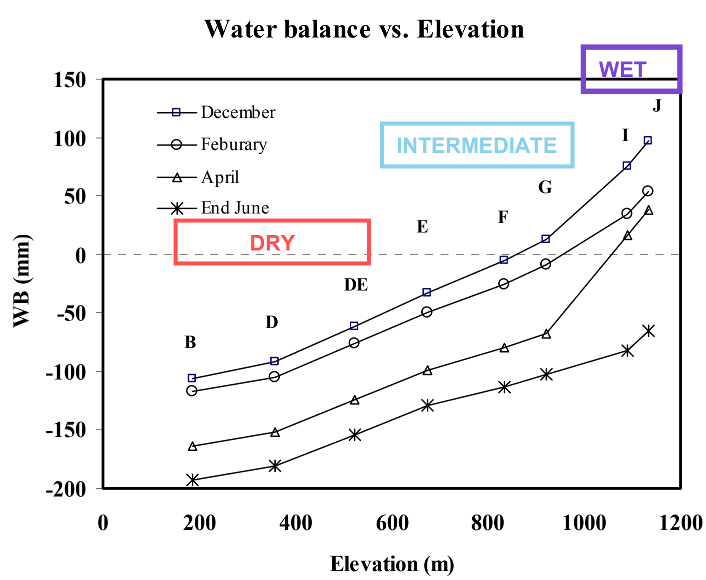

Figure 2. Water balance along the sample transects in different months (December to end of June)

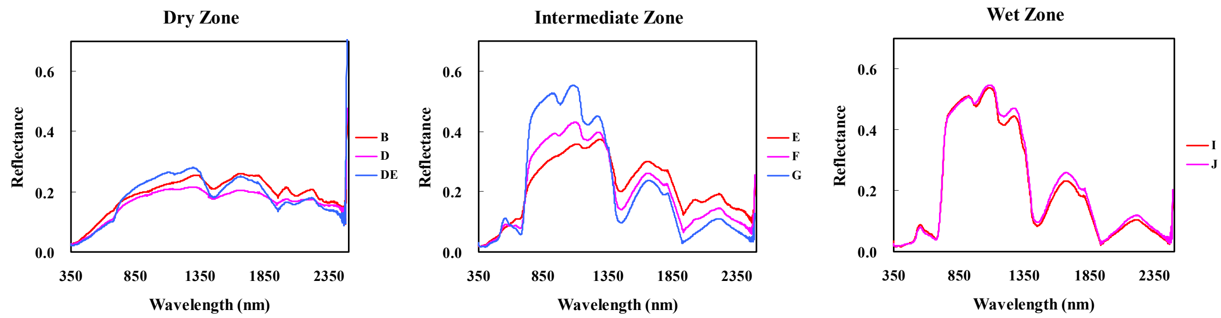

Figure 3. Mean reflectance measured in three climatic zones: a) dry, b) intermediate, and c) wet

Vegetation indices, NDVI and SAVI, plotted along the transects (Figure 4.a) provide a good insight into changes in grass as a function of water balance. These vegetation indices tend to saturate in the wet zone, between G and J. Transect F, which is the most heterogeneous, shows the largest variability expressed by standard deviation.

By analyzing the fractional cover changes (Figure 4.b), we are able to understand better changes in the land surface along the transects. The dry zone is strongly characterized by high

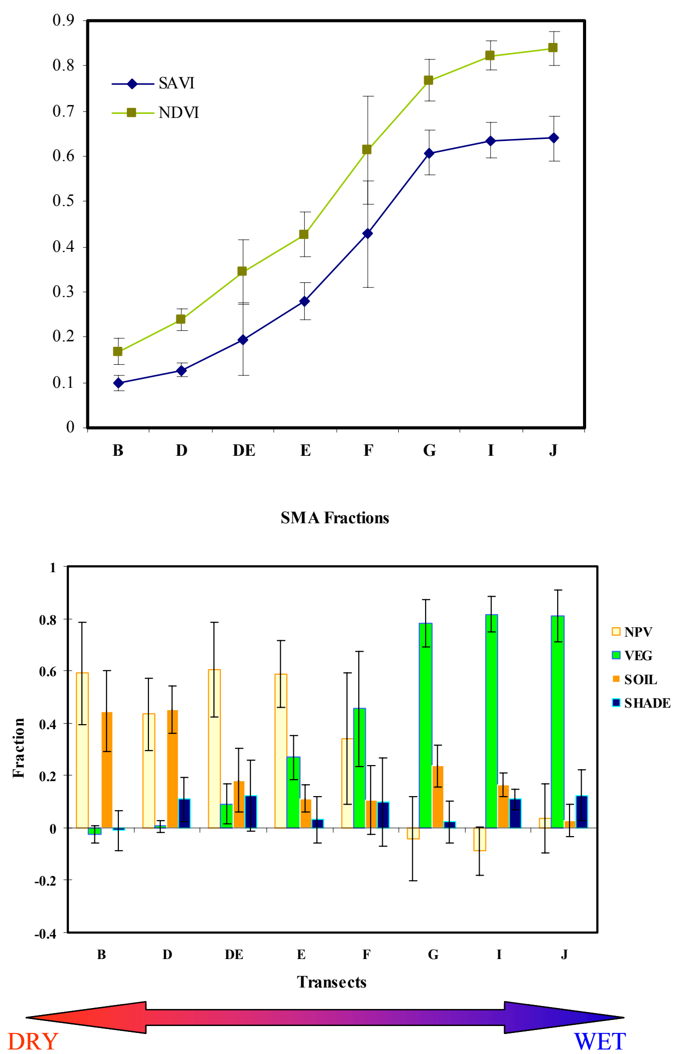

Figure 4. a) NDVI and SAVI along the sample transects; b) SMA fractions along the transects

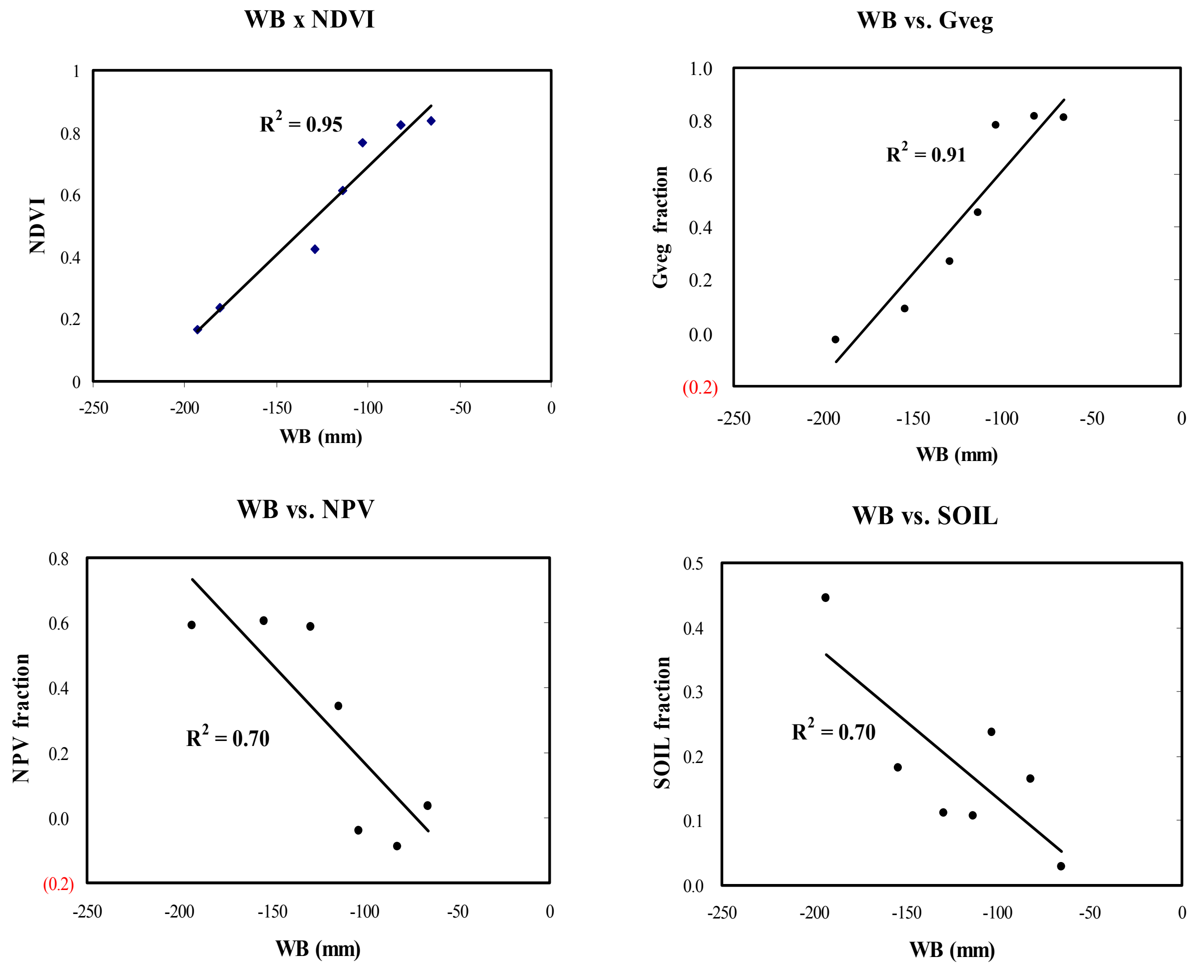

Figure 5. Correlation of WB with remotely sensed data

NPV and soil fractions, and low GV fraction, indicating sparse vegetation cover and high water stress on vegetation. NPV and soil fractions tend to decrease as water balance increases with elevation. GV fraction, on the other hand, shows an opposite trend, low in the dry zone and high in the wet zone. Note that in the transect F, the most heterogeneous site, a high variability is shown by a large variance as found in the vegetation indices previously.

In terms of relationships between climatic variation and vegetation changes derived from field spectra, NDVI and GV fractions showed a high positive linear correlation with water balance (R^2=0.95 and 0.91, for NDVI and GV, respectively), while soil and NPV are negatively correlated with water balance (Figure 5).

4.2 Soil physical properties and vegetation changes derived from hyperspectral data

With increasing rainfall along the climate gradient, there is a reduction in soil particle size and an increase in pore volume that enhances soil water holding capacity (Chadwick et al., 2003).

Coarse fragment % and pore volume formed the basis of the soil physical gradient and its impact on vegetation density and the vegetation indices. Coarse fragment % is the amount of soil fragments larger than 2mm contained in soil, while the pore volume refers to the total space or pore formed among soil particles, where water in soil is stored in. Figure 6 shows a negative correlation between these two variables. Smaller soil particles and the consequent greater porosity, leads to greater water holding capacity when compared with those areas with high coarse fragment %. Therefore sites B, D, and DE, both receive little annual rain and store relatively small amounts of water. Meanwhile, the higher elevation sites such as I and J, receive high levels of annual rainfall and with their large pore volumes can store more moisture. These variables also show good relationships with remotely sensed data, GV and NPV (Figure 7, only GV fraction is shown in the figures). Note that our spectra were collected in June-July, in the dry summer, in which water balance at the all sampling sites reaches negative, however we have just seem high vegetation signals from the wet zone (Figure 5). The grasses at sites I and J remain green even during the period of negative water balance because their elevated water holding capacity stores water for long periods.

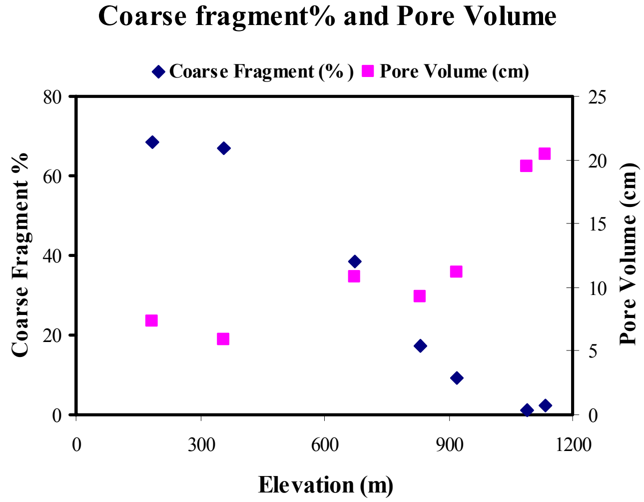

Figure 6. Coarse fragment% and pore volume along the transects

While water balance controls overall changes in vegetation along Kohala Mountain, the effects of soil physical properties on vegetation become more evident and more important in the dry summer when water balance is negative. Consequently, the combination of climate with soil properties is expected to be responsible for spatial and temporal changes in grassland in this region.

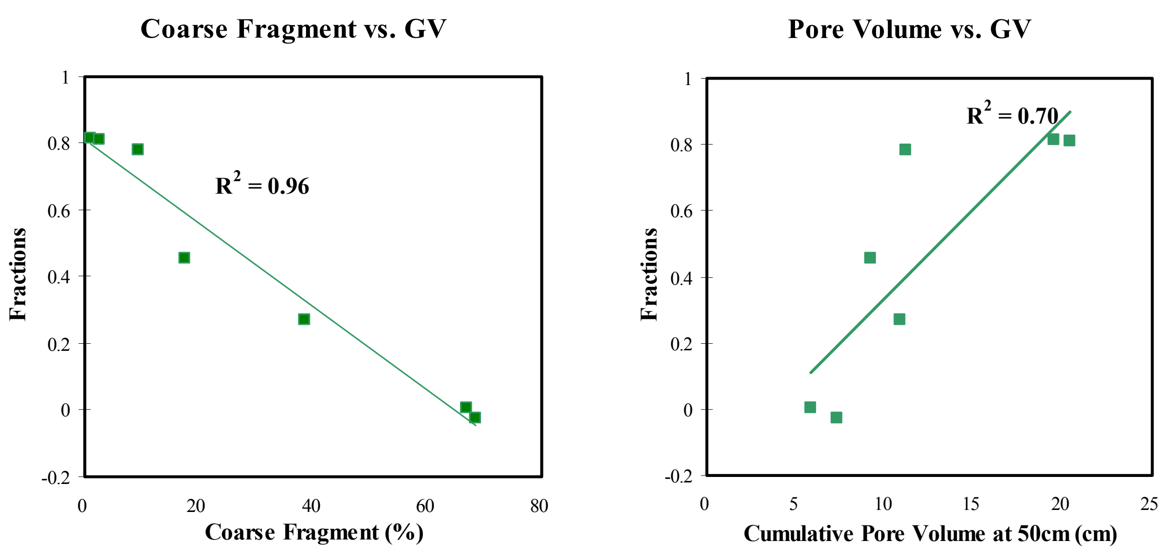

Figure 7. Correlation of GV with coarse fragment (left) and with pore volume (right)

5. CONCLUSIONS AND FUTURE RESEARCH

Kohala Mountain provides an ideal ecosystem to study interactions among climate, soil and vegetation. This study showed a simple application of hyperspectral data for characterizing the changes in grassland under climatic and soil gradients.

- Water balance is the major source of changes in grassland along Kohala Mountain, showing high correlation with vegetation changes derived from field level hyperspectral data.
- Soil physical properties related to water holding capacity also control the grass status on Kohala. However, the effects of soil physical properties are expected to become more evident and more important in the dry summer, when water balance reaches negative.
- Field level spectra provided good indicators of vegetation changes and fractional cover changes gave good insight into land cover changes along the transects.

The high correlation of vegetation changes with climate and soil properties can lead us to characterization of continuous land-surface changes by using AVIRIS data. In addition, it is recommendable to extend this study to other seasons (seasonal analysis).

6. ACKNOWLEDGEMENTS

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