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ScienceDirect
ISPRS Journal of Photogrammetry & Remote Sensing 62 (2007) 34–42
PHOTOGRAMMETRY & REMOTE SENSING
www.elsevier.com/locate/isprsjprs

Red edge shift and biochemical content in grass canopies

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Received 4 November 2005; received in revised form 1 February 2007; accepted 1 February 2007
Available online 1 March 2007

Abstract

The concentration of foliar nitrogen in tropical grass is one of the factors that explain the distribution of wildlife. Therefore, the remote sensing of foliar nitrogen contributes to a better understanding of wildlife feeding patterns. This study evaluated changes in the red edge position of the 680 nm continuum removed chlorophyll feature in the reflectance spectra of samples of *Cenchus ciliaris* grass grown in a greenhouse under three levels of nitrogen supply. Canopy spectral measurements from each treatment were recorded under controlled laboratory conditions over a four-week period using a GER 3700 spectroradiometer. Results indicate that the mean wavelength positions of the three fertilization treatments were statistically different. An increase in nitrogen supply yielded a shift in the red edge position to longer wavelengths. The red edge position, amplitude, slope at 713 nm and slope at 725 nm were significantly correlated to measured nitrogen concentration (bootstrapped $r=0.89$, -0.28, 0.63 and 0.75, respectively) even at canopy level. Based on these results, the red edge position is strongly correlated with biochemical concentration in plants compared to the other methods tested. The study provides conclusive evidence that confirms the strength of a red edge-nitrogen relationship that remains underused in remote sensing. This method is promising for estimating nutrient content in grasslands.

Keywords: nitrogen concentration; red edge position; continuum removal; bootstrapping; chlorophyll absorption feature

1. Introduction

The percentage of total digestible nutrients in plants is one of the major factors that explain the distribution of wildlife, especially in parks and nature reserves where human interference is minimal (Bailey et al., 1996; Grant et al., 2000). The nutrient content of forage, largely determined by foliar nitrogen concentration, is important for the health of grazing animals (van Soest, 1994). Therefore, the remote sensing of foliar nitrogen contributes to an understanding of wildlife and livestock feeding patterns.

Attempts to remotely sense foliar nitrogen at canopy level have been limited by the presence of water in fresh canopies that masks the biochemical absorption features, especially in the mid-infrared range (Clevers, 1999; Kokaly and Clark, 1999). In addition, leaf orientation, soil background effects, as well as atmospheric absorption further complicate the remote sensing of foliar biochemicals at canopy level (Asner et al., 2000).

Recently, studies have shown that the red edge is less sensitive to soil background and atmospheric effects and can provide information, not available from a

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0924-2716/$ - see front matter © 2007 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS). Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.isprsjprs.2007.02.001

combination of near infrared and visible spectral bands (Clevers, 1999; Clevers et al., 2000). The red edge position is the point of maximum slope in the vegetation reflectance spectra (Fillella and Penuelas, 1994) that occurs in the 680–750 nm region. This phenomenon is caused by strong chlorophyll absorption in the red spectrum and canopy scattering in the near infrared (Dawson and Curran, 1998). An increase in chlorophyll concentration or biomass results in the broadening of the absorption feature centered around 670 nm, causing the movement of the red edge position to longer wavelengths (Dawson and Curran, 1998). As a result, the red edge position has been successfully used in studies to estimate chlorophyll concentration, biomass and LAI (Curran et al., 1991; Danson and Plummer, 1995; Thomas and Gaussman, 1977).

Chlorophyll a and chlorophyll b concentration in plants have also been shown to correlate strongly with nitrogen (Haboudane et al., 2004; Hansen and Schjoerring, 2003; Katz et al., 1966; Penuelas et al., 1994). Nitrogen is related to protein synthesis, which promotes the photosynthetic process. The nitrogen deficiency disturbs the metabolic function of the chlorophyll, which is the photosynthetic element responsible for the absorption of electromagnetic radiation (Ponzoni and Goncalves, 1999). Therefore, studies have used the red edge–chlorophyll relationship to indirectly infer the nitrogen status of plants (Fillella and Penuelas, 1994; Jongschaap and Booij, 2004).

In this study, we hypothesize that, because chlorophyll largely determines the red edge shift, a strong correlation between the red edge position and nitrogen concentration is also expected. The objective of this study was to evaluate the response of the red edge measured at canopy level to a variation in the nitrogen supply and to establish the relationship between foliar nitrogen concentration and the red edge. The wavelength of the red edge position (λ_{re}), amplitude (reflectance at the maximum slope), and slope at 713 nm and 725 nm channels were compared. This study reports the results of an experiment in which we varied nitrogen supply in the soil to three groups of *Cenchrus ciliaris* grass grown in a greenhouse and measured canopy reflectance in the laboratory over a period of four-weeks.

2. Materials and methods

2.1. Plant preparation

Blue Buffalo grass (*C. ciliaris*) was sown in a greenhouse for this experiment. *C. ciliaris* is a sweet perennial grass that grows naturally in southern Africa and is widely used as pasture grass for ruminants. The grass grows from 10–150 cm high, is tufted, erect, branching and rooting at the nodes (Pooley, 1998). The grass grows quickly and is currently recommended for planting in dry land areas in order to provide pasture to ruminants (Pooley, 1998).

A total of 96 pots (10 l volume with a diameter of 26 cm and a height of 24 cm) were used for planting. Five seeds were sown in each pot in a greenhouse on 30 July 2001. The seedlings were grown under natural day light with a night temperature of 21 °C and a day temperature of 25 °C. The plants were supplied with an initial fertilization of 2.2 g of patent kali and 3.6 g of super phosphate per pot and were watered at least once every day.

The pots were randomly divided into three equal groups on 13 August 2001. To manipulate a variation in foliar concentration of nitrogen, the first group (called high nitrogen) was supplied with 3.4 ml (120 kg/ha) of ammonium nitrate per pot. The second group (called low nitrogen) was supplied with 1.14 ml (40 kg/ha) of ammonium nitrate per pot. This was supplied over a period of several days until the end of the harvesting period. No nitrogen was added to the control group. The pots were arranged in blocks and rotated once a week to minimize any effects of microclimate on the experiment.

2.2. Canopy spectral measurements

To manipulate variations in the concentrations of chemicals, measurements were taken at the beginning of every week for four-weeks from September 3 to 31 2001. Measurements were taken from this date onwards because the grass had grown to an extent that it largely covered the soil, thus minimizing the background effects. The plants were transferred in their pots from the greenhouse to a laboratory on each day of a measurement. A total of eight pots from each treatment were measured every week. Measurements were done under laboratory conditions in order to control for sources of variation not related to plant vigor, such as change in illumination angle and atmospheric effects (Luther and Carroll, 1999).

Reflectance measurements were done using a GER 3700 spectroradiometer. The GER 3700 (Geophysical and Environmental Research corp.) is a three dispersion grating spectroradiometer using Si and PbS detectors with a single field of view. The wavelength range is 350–2500 nm with a resolution of 1.5 nm in the 350–1050 nm, 6.2 nm in the 1050–1900 nm range and 9.5 nm in the 1900–2500 nm range. The sensor, with a field of view of 3°, was mounted on a tripod and positioned 2 m