REMOTE SENSING METHODS FOR THE EVALUATION OF THE MESQUITE TREE (*Prosopis juliflora*) ENVIRONMENTAL ADAPTATION TO SEMI-ARID AFRICA

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Abstract — In this study a remote sensing approach for the mesquite tree (*Prosopis juliflora*) control is proposed. The mesquite tree is well known for its high adaptability to arid and semi-arid conditions and characterized by very high water use efficiency. Introduction of the mesquite has caused several environmental problems in Sudan. In this study, to monitor mesquite water use efficiency the concept of a Normalized Difference Infrared Index (NDII), which is defined as the ratio of actual to foliar water content, have been applied and compared with the ground measurements of stomatal conductance (mmol. m−2. s−1), field spectral, volumetric soil water content. As results, on the base of the PALSAR L-band microwave polarimetric backscatter coefficient, the soil moisture (in bare soil area) and surface roughness (in dense forest covered area) could be estimated with a good accuracy for bare-soil surfaces.

Keywords —mesquite *(Prosopis juliflora)* control, NDII, backscatter coefficient, Africa

I. INTRODUCTION

Studies on the plants adaptation to environment are very important for evaluation of the vegetation response to global climate changes. Vegetation water content is important ecophysiological parameter that provides information on the vegetation's environmental adaptation and used to determine the plants water stress. An accurate estimate of the plant water content is significant key in evaluating the strategic expansion of the invasive mesquite (*Prosopis juliflora*) in semi-arid area of Africa. The mesquite has a problematic spreading that threatens agriculture in vast areas of eastern Sudan, including Tokar Delta, Gash Delta, numerous sites along Red Sea coast area and irrigated farmland of Kassala plain. According to Brown et al. [1], in 1917 the mesquite tree were introduced into Sudan from South Africa and Egypt and planted in Khartoum. The tree has characteristics of high drought tolerance, sand dunes fixing, and could also be used as fodder for animals. The mesquite usage, beside sand dune fixation is limited to firewood and charcoal production. More than 90% of mesquite is thought spread in eastern Sudan, where livestock keeping and subsistence cultivation constitute the main source of income. Invasive mesquite tends to form dense and impenetrable thickets. It's highly competitive nature leads to reduce grass cover, stocking density, and threatens the livelihood of traditional pastoralists. Its invasion into agricultural land, along irrigation channels and water courses is also a major problem. The expected high water table at the lower streams of Tokar, Gash Delta and Kassala plain seasonal river in addition to the fertile soil, contribute to the menacing of mesquite spread. Previous studies [2] in other part of the world clearly showed that eradication of mesquite is neither desirable nor tenable.

Mesquite can detect even very tiny soil moisture and grow to various conditions. Some of the many adaptive abilities that allow mesquite to thrive under such conditions include ability of roots to adapt to a wide variety of soil conditions. Roots can grow upwards towards the soil surface to capitalize on little rainfall, but can also grow to depths of 80 m and extend laterally more than 30 m. This is the most extensive root system of any plant in the world [3].

II. METHODOLOGY AND RESULT

A. Measurement of stomatal conductance

In the eastern Sudan's semi-arid land, adaptation of the mesquite to a variety of habitats may be related to a plasticity of root system distribution. Mesquite tree uses deep ground water with a taproot in the dry season and the soil water with a lateral roots in wet season. When available, mesquite will exploit sources of deep water by growing a taproot. Mesquite can also persist on sites that have little or no ground water by growing lengthy shallow lateral roots. Therefore, most of the native plants growing around a mesquite tree become withered and died.

Moreover the mesquite can control the leaf water evaporation and survive even in the driest season, because the mesquite water use efficiency is higher than those of native species. Fig. 1 shows the parameters of the stomatal conductance (mmol. m−2. s−1) in native plants and mesquite. Beginning from 11:00 am, most of the native plants goes into "nap" time and reduce evapotranspiration (ET) when air temperatures are near 40 degrees. However, mesquite is gradually reducing ET from 9:00 am, and remaine low evapotranspiration during the whole day.

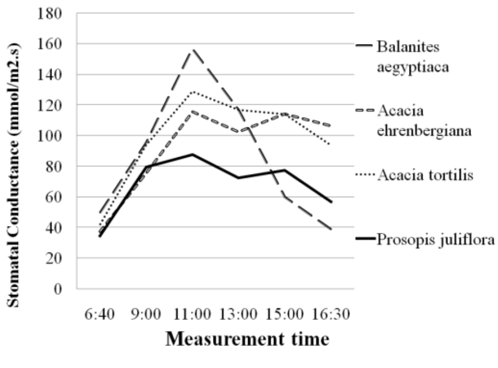

Fig. 1. Comparison of the stomatal conductance (mmol m−2 s−1) in native plants and invasive species (mesquite) at semi-arid area of Kassala, Sudan (Nov. 7, 2010).

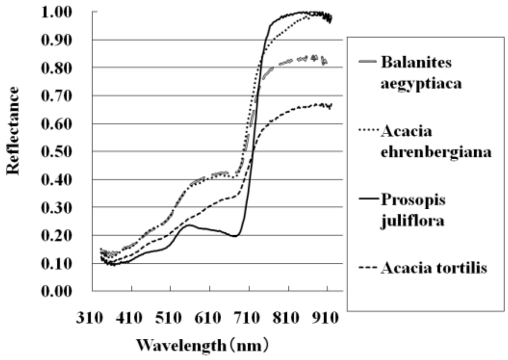

Fig. 2. The field spectral reflectance of native plants and invasive species (mesquite) in semi-arid area of Kassala, Sudan (Nov. 7th, 2010)

B. Normalized Difference Infrared Index

Since leaf chlorophyll absorbs red light energy, and reflect near-infrared (NIR) light energy of sunlight. Therefore, vigorously growing healthy vegetation has low red-light reflectance (due to its chlorophyll) and high near-infrared reflectance (due to its total biomass). Fig. 2 shows parameters of the spectral reflectance of mesquite trees and the surrounding native plants. Mesquite has low red-light reflectance and high NIR reflectance. Moreover, comparison of the mesquite's absorption of red light and the reflection of NIR light with those of other native plants, showed that the mesquite was more healthy and vigorously growing. To quantify water stress level in aboriginal and invasive species we are followed. Moran et al. [4] investigated the effect of water stress on canopy architecture in alfalfa (*Medicago sativa L.*) and the sequential effect on canopy reflectance. They found water-stressed canopies to have a lower spectral reflectance in the NIR wavelength and lower spectral absorption in the red wavelength when compared with unstressed canopies. A ratio of the two wavelengths was most successful in estimating the onset of stress. In our study as shown in Fig. 2, in the same habitat, the native plants have more water-stressed growing than the mesquite. The ratio of NIR and red wavelength in the mesquite was 4.5 while those of a native plant were only 1.9.

We investigated the concept of a Normalized Difference Infrared Index (NDII), which is defined as the ratio of actual to foliar water content. The foliar water content is often divided by the density of liquid water to derive the equivalent water thickness (EWT). EWT is useful because the canopy EWT is equal to the leaf EWT multiplied by the leaf area index (LAI). Leaf reflectance at short wave infrared (SWIR) wavelength was increases linearly with respect to leaf reflectance at NIR for a decrease in leaf EWT. The measurement can be calculated from remotely sensed data (NIR and SWIR). Hardisky et al. [5] defined the NDII as:

$$NDII = \frac{NIR - SWIR}{NIR + SWIR} \qquad (1)$$

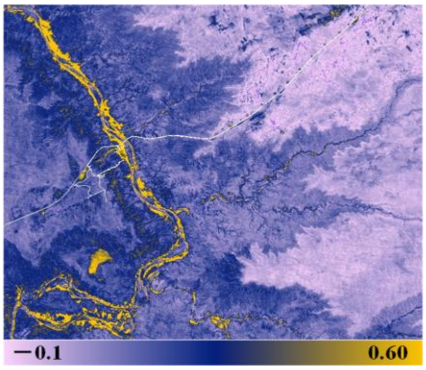

Fig. 3. NDII map calculated from Landsat TM5 data (where, yellow color shows mesquite trees distribution. Mesquite was expanded along the bank of a river. Dec. 11th, 2009).

This is could be calculated from the Landsat 5 Thematic Mapper (TM) bands 4 and 7. Fig. 3 shows the NDII image calculated from Landsat 5 spectral band 4 and band 7. This index exhibits the ability to evaluate the invasion strategy of alien species mesquite. As shown in Fig. 3, the mesquite expansion followed a high soil moisture area along the banks of a river.

C. Measurement of polarimetric backscattering

The field measures using a hand-held soil moisture measurement system (©Hydrosense) showed that the volumetric soil water content was only 3-5% in area under the mesquite or around the mesquite trees at radius of 10 meters. As the amount of water contained in soil becomes greater, specific inductive capacity of the whole soil increases in proportion, and as a result, backscatter strength increases. In this way, analysis of backscatter strength leads to estimate the amount of water content in target land area. Based on the accurate scattering model, both the soil moisture and surface roughness can be retrieved from the measurements of polarimetric backscattering with a good accuracy for bare-soil surfaces. It is well known that the retrieval of soil moisture in vegetated surface from the microwave backscatter coefficient is affected by surface roughness. In bare soil area of Atbara River basin (in Eastern Sudan), we found good relationship between field measure soil moisture (Mv) and ALOS/PALSAR L-band backscatter coefficient ($M_v = 4.24\sigma^0_{baresoil} + 126.4$, R^2=0.985). However, for surfaces with vegetation cover, the soil moisture retrieval is a challenging problem because of complicate scattering mechanisms in the vegetation canopy. Except for dense forest canopies, backscatter from vegetation is due to surface, volume and multiple scattering [6]:

$$\sigma^0_{total} = \sigma^0_{surface} + \sigma^0_{volume} + \sigma^0_{interaction} \qquad (2)$$

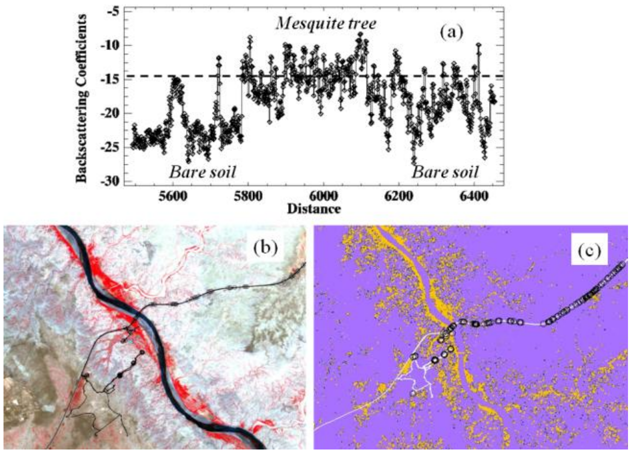

Fig. 4. The total microwave backscattering coefficient (σ^0) of study area in Sep. 18th, 2010 (where, (a): shows horizontal profile of backscattering coefficient (σ^0) of cross the mesquite covered area and bare-soil area; (b): shows R-G-B color composition image by ALOS AVNIR-2 Band 4-3-2 (where, the light red color shows mesquite trees; black lines: GPS track; black points: field measure points); and (c): shows backscattering coefficient (σ^0) image calculated from high resolution L-band PALSAR HH/HV polarimetric data. Where, yellow color shows the backscatter coefficient pixels and (σ^0_{total} > -15); white lines: GPS track; black points: field measure points).

A semi-empirical polarimetric backscattering model for bare soil surfaces is inverted directly to retrieve both the volumetric soil moisture content and the RMS surface roughness height from multipolarized radar observations [7]. However, we found that the PALSAR L-band has had difficulties to penetrate the high dense mesquite trees. Fig. 4 shows the total backscatter coefficient $\sigma^0[dB] = 10\log\sigma^0[m^2m^{-2}]$ of study area calculated from ALOS satellite PALSAR L-band HH/HV polarimetric data. As show in Fig. 4(a), backscatter value range of the mesquite covered area was ($\sigma^0_{total} > -15$); and for the native plants (Acacia ehrenbergiana, Acacia tortilis, Balanites aegyptiaca) are ($-15 > \sigma^0_{total} > -19$); while bare soil are was ($\sigma^0_{total} < -20$).

III. DISCUSSION

The mesquite trees (*Prosopis juliflora*) grow in arrays of habitats, and characterized by very high water use efficiency. In this study we applied ground measurement of the plants stomatal conductance and satellite based Normalized Difference Infrared Index (NDII) to detect the foliar water content, and based on NDII success tried to retrieve the mesquite tree distribution area.

If vegetation water content can be estimated independently using reflectance in the SWIR, then the retrievals of soil moisture content will be more accurate. The problem is that SWIR reflectances are dominated by foliar water content and are not affected by stem water content. However, plants often have allometric relationships between foliar and stem mass, so estimation of foliar water content from SWIR reflectance would allow prediction of vegetation water content. We found that the high dense mesquite trees make difficulties for the penetration of the PALSAR L-band. Based on the accurate scattering model, both the soil moisture and surface roughness can be retrieved from the measurements of the polarimetric backscatter with a good accuracy for bare-soil surfaces. However, for areas covered with dense mesquite trees, the soil moisture retrieval is a challenging problem because of complicate scattering mechanisms in the mesquite canopy. So far, additional studies on the estimation of the mesquite biomass using PALSAR L-band microwave data are needed.

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