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Effect of Chlorophyll Content and Solar Irradiance on Spectral Reflectance of Vegetation Canopies Acquired by Spectroradiometer

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Reaserch Article

Effect of Chlorophyll Content and Solar Irradiance on Spectral Reflectance of Vegetation Canopies Acquired by Spectroradiometer

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Abstract

The aims of the study were: (i) to observe the effect of leaf chlorophyll content, Solar Irradiance and Normalized Difference Vegetation Index (NDVI) on spectral reflectance at Visible (Blue,Green,Red), Near Infrared (NIR) and Short Wave Infrared (SWIR) spectrum for a given number of vegetation types including Rongon (Ixora Coccinea), Hibiscus, Jhau, Grass and Togor (Tabernaemontana Divaricata).(ii) to investigate the relationship of Solar Irradiance with Normalized Difference Vegetation Index (NDVI) for the same number of vegetation types. This study used a five band hand-held spectro-radiometer "Multispectral Radiometer MSR-5" centered at wavelength 485nm, 560nm, 660nm, 830nm and 1650nm corresponding to bands 2, 3, 4, 5, 6 of Landsat 8 operational Land Imager (OLI) sensor. This spectro-radiometer provides solar irradiance and spectral reflectance values in the visible, NIR and SWIR spectrum which indirectly help to calculate Normalized Difference Vegetation Index (NDVI) for the given number of vegetation types. This study also used a Chlorophyll Meter (SPAD 502) to estimate chlorophyll concentration from the leaf of the vegetation types. The result shows that the value of the spectral reflectance correlated linearly with chlorophyll content at wavelength at 560nm and 1650 nm where the coefficient of determination R^2 is 0.8761 and 0.6289 respectively. The spectral reflectance correlated inversely with NDVI at wavelength 485nm and 660nm where the coefficient of determination R^2 was 0.5317 and 0.6191 respectively. This result also shows that solar irradiance relates inversely with chlorophyll content at wavelength 830nm where the coefficient of determination R^2 was 0.8523.Lastly we have found that solar irradiance correlated inversely with NDVI where the coefficient of determination R^2 was 0.7617.

Keywords: Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI)**,** chlorophyll content, Spectral Reflectance

Introduction

The quantitative and reliable interpretation of data acquired from satellite platform requires a thorough understanding of the factors and condition that determine the reflectance at satellite altitude. Though the satellite data offers the most suitable way of monitoring vegetation condition but still a lack of proper methodology to extract relevant vegetation information is noticed. Spectral Reflectance, Normalized Difference Vegetation Index (NDVI) and biophysical parameters such as vegetation Leaf Area Index (LAI), Chlorophyll etc. are not same for all the vegetation. Spectral Reflectance can be measured by spectro-radiometer (Huang, et al. 2013) and chlorophyll can be measured by SPAD readings (Hu, et al., 2014; Sultana et al., 2019; Mehta et al., 2021; Panchal et al., 2021). By taking the spectral reflection of different vegetation and the biophysical parameters of the same vegetation, it was possible to interpret different vegetation and subtract them from each other. Chlorophyll content is important parameter for analysing photosynthetic potential, nitrogen status, and productivity of different crops (Li et al. 2019; Curran et al. 1990; Chen, et al. 2007; Gitelson, et al. 2003). Thus, estimating chlorophyll content is valuable from a physiological perspective (Croft et al., 2017; Richardson, et al., 2002).

Leaf chlorophyll absorbs incident light in specific wavebands, which enables us to detect chlorophyll content using optical methods for a wide variety of plant species (Gamon and Surfus, 1999; Gitelson, et al., 2003; Simsand Gamon, 2002).Also Spectral reflectance another important parameter for observing plant health, crop production assessment and water quality assessment (Chander, et al. 2019). In recent year's remote sensing technology have been introduced to evaluate chlorophyll content using spectral reflectance, since leaf chlorophyll content can provide information concerning the physiological state of a leaf or plant (Zhang, et al. 2014). Several vegetation indices estimated from remote sensing data have been considered for assessing the status of leaf chlorophyll content, plant biomass, production, and vegetation health status (Chen, et al. 2007).By considering the importance of leaf chlorophyll parameters many scientist have been incorporated the relationship between leaf chlorophyll content with spectral reflectance for calculating chlorophyll content properly (Dawson, et al. 1998; Jacquemoud, et al.1996).

Development of Satellite-based Remote Sensing (RS) technology significantly enriched the science of acquisition and analysis of geo-information in various sectors of earth sciences. Proper utilization of RS technology provides systematic, reliable and timely information on natural resources, natural disasters and the dynamic environment around. This information is essential for resources analysis, environmental impact analysis, disaster monitoring and development related planning at different levels etc.

However, utilization of such data in a particular geo-discipline requires specific and appropriate theme oriented algorithm or analytical procedure for inferring relevant information. Diversity in geo-environmental condition and variation in the nature of utilization in different parts of the world necessitate region specific development, adaptation and utilization of remote sensing procedures for maximizing the precision and benefit of such modern technology. Bangladesh has to make proper utilization of the latest development of satellite based remote sensing technology (Islam et al., 2016; Tazneen et al., 2021).

The purpose of the present paper is observe the effect of leaf chlorophyll content, Solar Irradiance and Normalized Difference Vegetation Index (NDVI) on spectral reflectance at Visible(Blue,Green,Red), Near Infrared (NIR) and Short Wave Infrared (SWIR) spectrum for a given number of vegetation types including Rongon (Ixora Coccinea), Hibiscus, Jhau, Grass and Togor(Tabernaemontana Divaricata) and also investigate the relationship of Solar Irradiance with Normalized Difference Vegetation Index (NDVI) for the same number of vegetation types.

Methodology

Study Area

Measurements were taken from Bangladesh Space Research and Remote Sensing Organization (SPARRSO) premises situating at the latitude 23˚46′50.99713″ and longitude 90˚22′39.33384″. As a preliminary approach measurements of spectral reflectance and different biophysical parameters were performed in nearby areas over surface cover types e.g., grass land, Rongon, Jhau, Hibiscus, and concrete road. The fields were mostly dry.

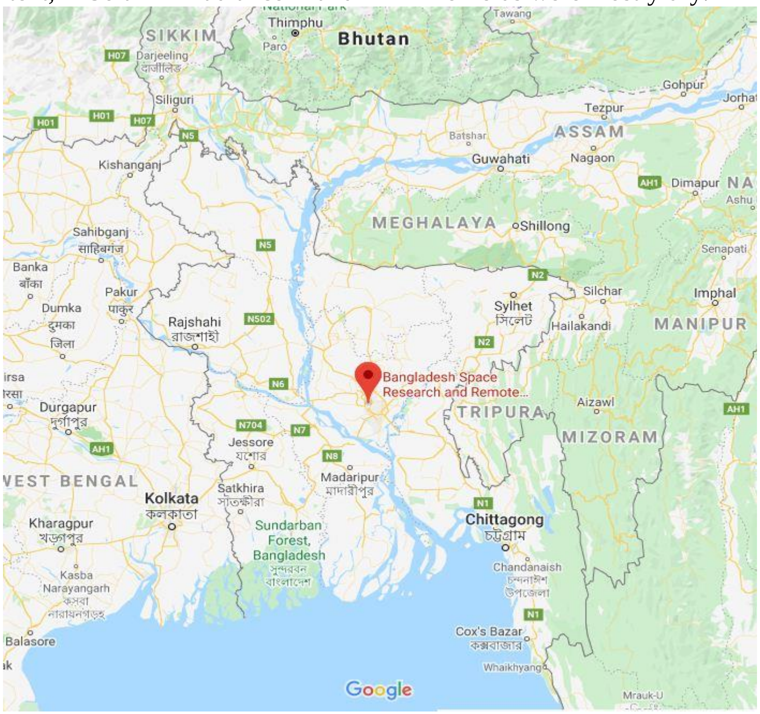

Fig. 1. Study Area

Data Acquisition

Reflectance and Solar Irradiance data acquisition using Radiometer MSR-5

Surface Reflectance data has been acquired by using Multispectral Radiometer, MSR-5. Multispectral Radiometer, MSR-5 has five spectral bands. Five detectors are settled in the wavelength region 485nm, 560 nm, 660 nm, 830 nm and 1650 nm respectively which corresponding to bands 2, 3, 4, 5 and 6 of Landsat 8 Operational Land Imager (OLI) sensor. Also, Multispectral Radiometer, MSR-5 can also directly measure the Solar Irradiance. Values of Surface Reflectance at different wavelength, Solar Irradiance and NDVI measured from handheld Spectro-radiometer MSR-5 have been shown in Table-2 (Ahammad T et al. 2019; Huang W et al. 2013).

NDVI (Normalized Difference Vegetation Index) calculation using Reflectance Data

Among the five detectors of Radiometer MSR-5, 660nm and 830nm detectors are sensitive to visible red and near infrared wavelength. Reflectance found in this two band are helpful to evaluate Normalized Difference Vegetation Index (NDVI) (Ahammad T et al. 2019).

Written mathematically, the formula is:

$$\mathrm{NDVI} = \frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{VIS}}}{\rho_{\mathrm{NIR}} + \rho_{\mathrm{VIS}}} \qquad \text{(Eq. 1)}$$

ρ_{VIS} And ρ_{NIR} are the reflectance in the visible and near infrared region of the solar spectrum respectively (Karnieli A et al. 2010; Trishchenko AP et all 2001; Hatfield J.L. and Prueger J.H. 2010; Zoran M and Stefan S 2006).

In general, if there is much more reflected radiation in near-infrared wavelengths than in visible wavelengths, then the vegetation in that pixel is likely to be dense and may contain some type of forest. If there is very little difference in the intensity of visible and near-infrared wavelengths reflected, then the vegetation is probably sparse and may consist of grassland, tundra, or desert. Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaves gives a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves (Weier J and Herring D 2000).

Biophysical parameters measured at the field level using RS field equipment

In remote sensing information retrieval system, proper interpretation and fruitful application of the acquired satellite data require ground-based characterization and validation of Earth's surface properties. The methodology necessitates incorporation of selected cluster-based ground measurements of biophysical parameters regulating Earth's geo-bio-hydro-environmental condition, e.g., soil moisture, rate of evapotranspiration by different Earth's surface features, vegetation properties like leaf density, chlorophyll concentration, fractional vegetation cover, amount of absorbed photo synthetically active radiation of plants etc. As such observation on different biophysical surface parameters of the Earth is very essential (Ahammad, et al. 2019).

Fig. 2. Digital Photographic Images of (a)Rongon (b)Jhau (c)Togor (d)Hibiscus (e)Grass

Table 1. Remote sensing field equipment for measurement of biophysical variables

Ground Truth Equipment	Functions
Spectroradiometer-MSR5	Spectral Reflectance measurements of different surface features
Chlorophyll Meter	Chlorophyll meter instantly measures the amount of chlorophyll content, a key indicator of plant health.
Handheld GPS	Geo-referencing of raster images, positioning of surface features

Table 2. Reflectance and Irradiance value of different types as measured by the Radiometer

Vegetation Name	Solar Irradiance	Wavelength 485 nm	560 nm	660 nm	830 nm	1650 nm	NDVI
Rongon	2243	2.77	7.22	3.13	44.19	12.54	0.87
Hibiscus	2260	3.62	8.39	3.94	43.24	12.80	0.83
Jhau	2448	2.20	4.86	2.53	23.85	7.28	0.81
Grass	2472	4.42	6.90	5.07	31.62	13.03	0.72
Togor	2221	2.48	6.63	2.62	52.88	14.93	0.91

Table 3. Chlorophyll content corresponding to different vegetation types as measured at the field level using Chlorophyll Meter

Vegetation type	Latitude	Longitude	Chlorophyll content
Rongon	23˚46´51.14401″	90˚22´43.92133″	45.8
Hibiscus	23˚46´51.10765″	90˚22´44.40337″	54.8
Jhau	23˚46´50.88853″	90˚22´44.08657″	11.6
Togor	23˚46´50.75053″	90˚22´43.56277″	51.5
Grass	23˚46´31.03817″	90˚22´40.11396″	38.7

Different parameters govern the spectral response of a vegetation canopy. So an extensive field measurement was carried out to quantify the associated parameters. A number of RS ground truth equipment has been used under this research to make measurements at field level of various biophysical parameters of crop canopy. In addition, radiometric measurements were made. Measurements began at about 12.00 am. The radiometer was placed about 180 cm above the ground surface and the measurement were carried out. The sky was mostly cloud-free with a medium range of visibility. The biophysical parameters which have been measured is shown in Table-1.

Result

Variation of Spectral Reflectance with Chlorophyll

Surface Reflectance is a very important parameter to classify different vegetation. Absorption and Reflectance of different canopy is different due to biophysical structure. Also Reflectance of each canopy is not same in all wavelength regions. Chlorophyll is another important parameter which impact on reflectance. In this study firstly we examine the effect of chlorophyll on spectral reflectance at wavelength region 485nm, 560 nm, 660 nm, 830 nm and 1650 nm respectively. In this study we have seen reflectance at 560nm and 1650 nm varies linearly with the chlorophyll content where the coefficient of determination R^2 is 0.8761 and 0.6289 respectively. In other three wavelength region we have not found any significant correlation where the coefficient of determination R^2 is 0.5668, 0.4888 and 0.2836at 485nm, 660nm and 8300nm respectively The correlation of Spectral Reflectance with Chlorophyll content of different vegetation as obtained through measurement at field site using RS equipment is shown in Figure-2(a), Figure-2(b), Figure-2(c), Figure-2(d) and Figure-2(e) respectively.

Relation of Spectral Reflectance with NDVI

Normalized Difference vegetation Index is a very crucial parameter to quantify the status of the vegetation. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves [2].Also variation of NDVI at different growth stage of vegetation is not same for all canopy. In the second part of the study we have examined the relation of spectral reflectance at different wavelength region with NDVI for the sample canopies. In this study we have seen NDVI has negative correlation with reflectance at 485nm and 660nm wavelength where the coefficient of determination R^2 is 0.5317 and 0.6191 respectively. On the other hand, NDVI has positive correlation with reflectance at 830nm where the coefficient of determination R^2 is 0.5549. We have not found any significant correlation at 560nm and 1650nm wavelength where the coefficient of determination R^2 is 0.0072 and 0.0845 respectively .The correlation of Spectral Reflectance with NDVI of different vegetation as obtained through measurement at field site using RS equipment is shown in Figure-3(a), Figure-3(b), Figure-3(c), Figure-3(d) and Figure-3(e) respectively.

Correlation of Spectral Reflectance with Solar Irradiance

Solar Irradiance is the source of all energy. When solar energy comes to the earth surface some portion of it is absorbed by different vegetation for making their food and the remaining portion of it is reflected back. By collecting the reflectance we can distinguish different crop as well as their health. In the third part of the study we have examined the correlation of solar irradiance with spectral reflectance at wavelength region 485nm, 560 nm, 660 nm, 830 nm and 1650 nm respectively for five types of study canopies. In this study we found only a negative correlation at 830nm wavelength region where the coefficient of determination R^2 is 0.8523. We have not found any significant correlation at other wavelength region where the coefficient of determination R^2 is 0.1028, 0.3113, 0.1606 and 0.3616 at wavelength 485nm, 560 nm, 660 nm and 1650 nm respectively. The correlation of Spectral Reflectance with Solar Irradiance of different vegetation as obtained through measurement at field site using RS equipment is shown in Figure-4(a), Figure-4(b), Figure-4(c), Figure-4(d) and Figure-4(e) respectively.

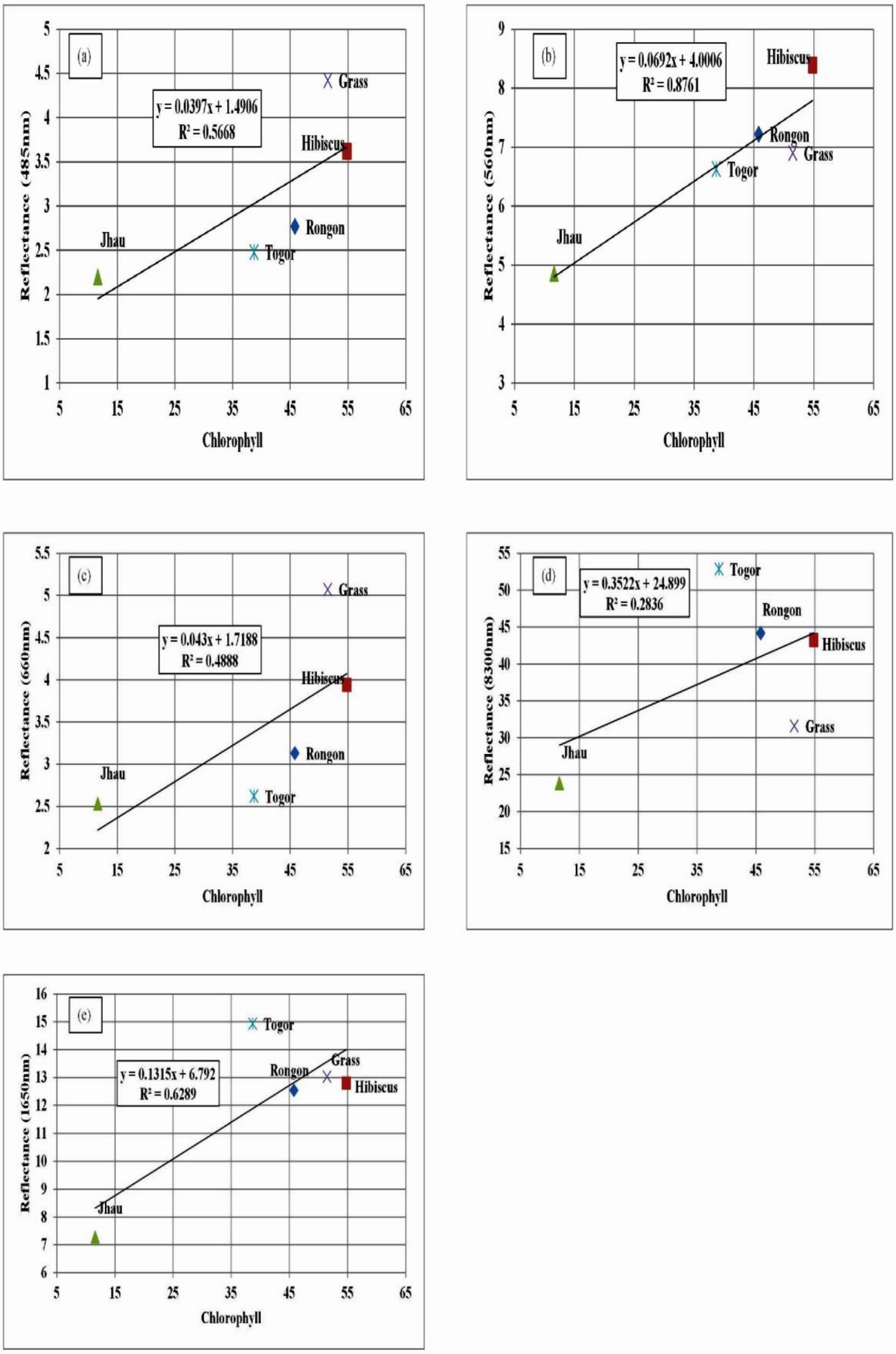

Fig. 2.Variation of Spectral Reflectance Characteristics with Chlorophyll of different Vegetation (a) 485nm (b) 560nm (c) 660nm (d) 830nm (e) 1650nm.

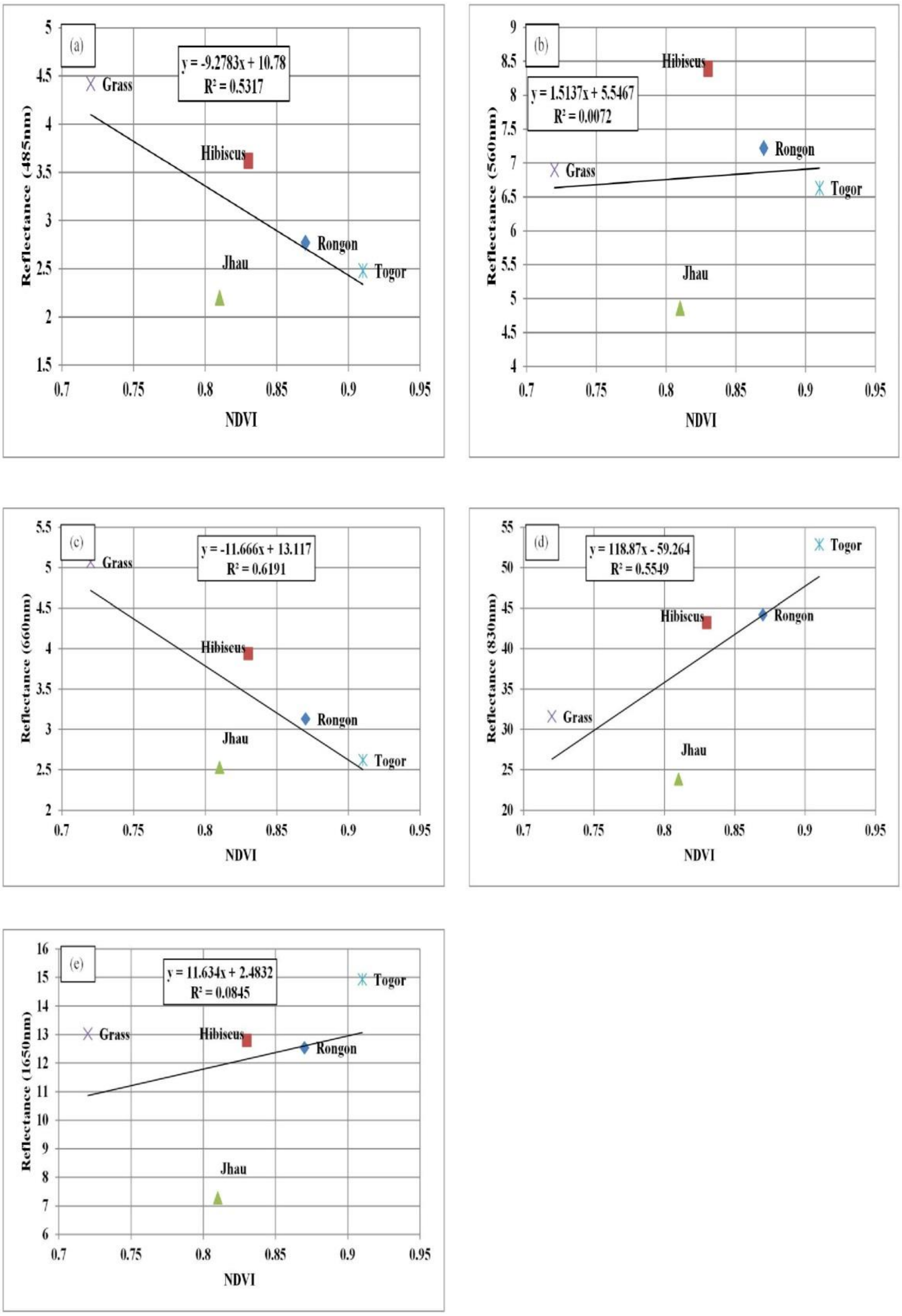

Fig. 3.Variation of Spectral Reflectance Characteristics with NDVI of different Vegetation (a) 485nm (b) 560nm (c) 660nm (d) 830nm (e) 1650nm

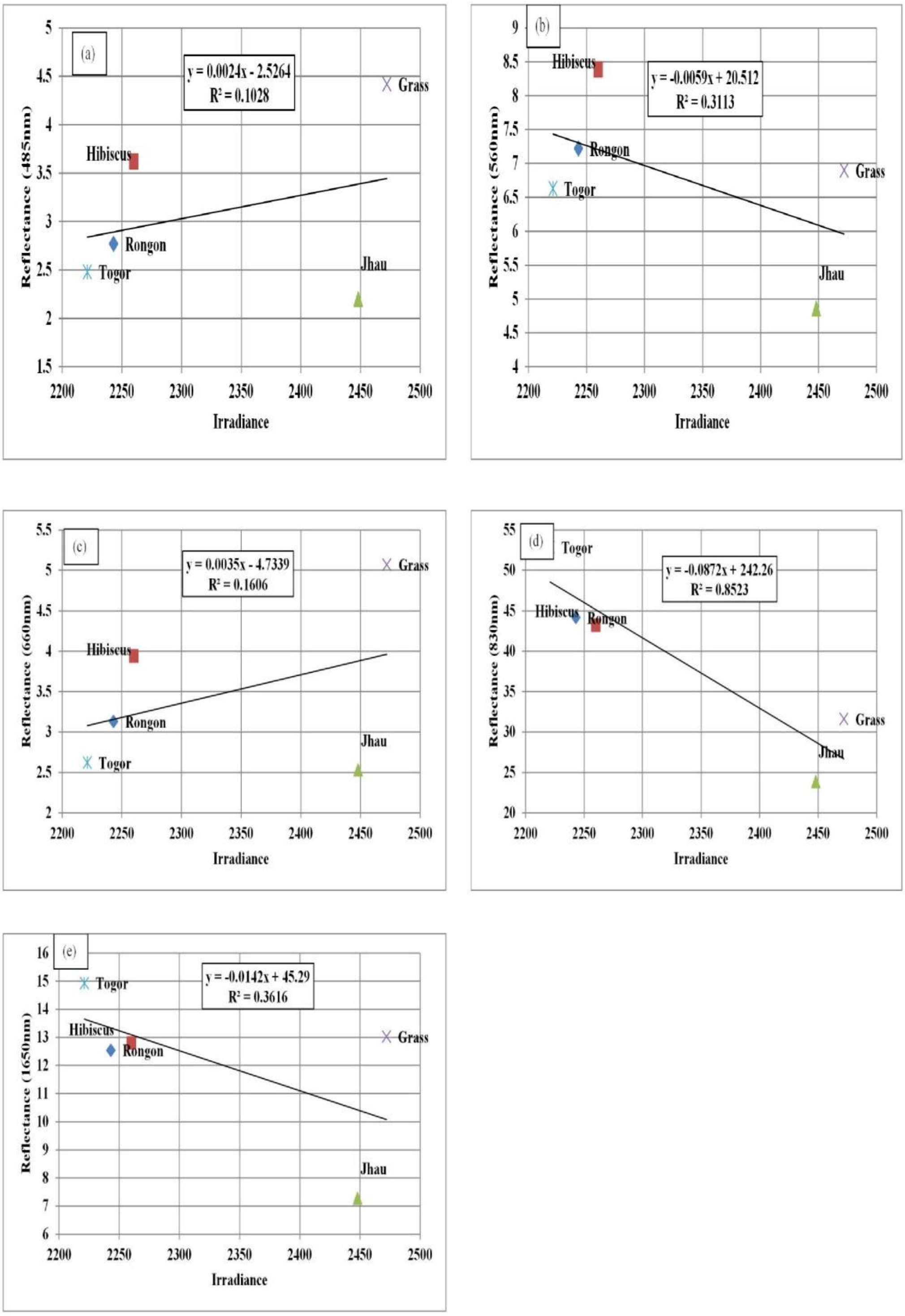

Fig. 4.Variation of Spectral Reflectance Characteristics with Solar Irradiance of different Vegetation (a) 485nm (b) 560nm (c) 660nm (d) 830nm (e) 1650nm.

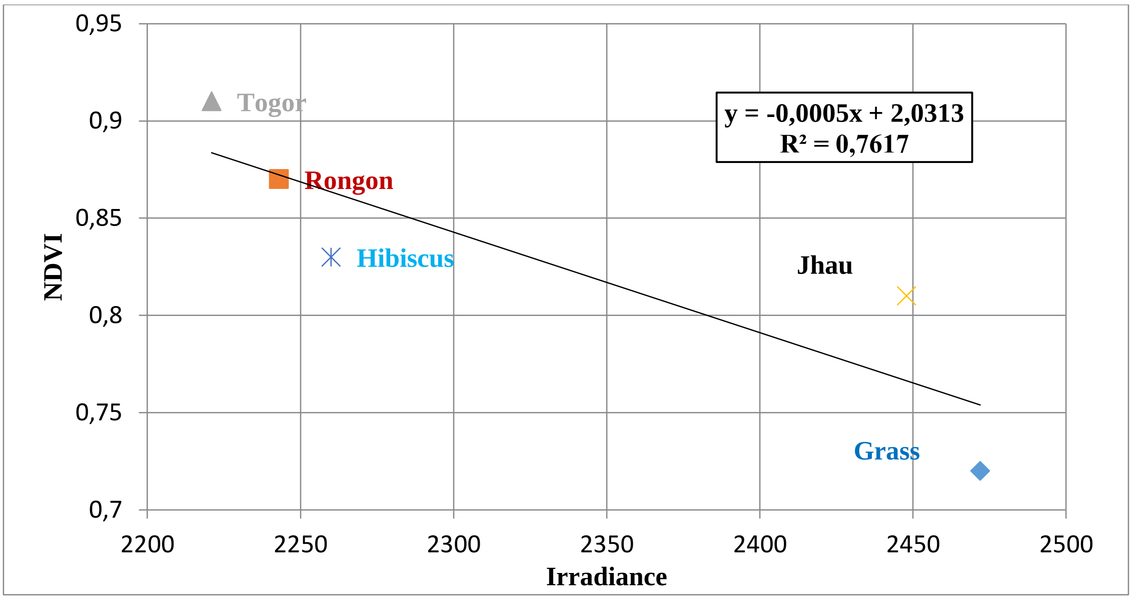

Fig.5. Variation of NDVI with Irradiance of different vegetation

Correlation of NDVI with Solar Irradiance

When solar radiation comes to the earth it is absorbed at different spectrum such as Visible (485nm, 560 nm, and 660 nm), Near Infrared (830nm) and Mid-Infrared (1650nm).Among them only Near Infrared (830nm) and Red (660nm) have been used to calculate NDVI. In the last part of the study we have examined the variation of NDVI with solar irradiance. In the study we have seen NDVI correlated inversely with solar irradiance where coefficient of determination R^2 is 0.7617. Variation of NDVI with Irradiance of different vegetation as obtained through measurement at field site using RS equipment is shown in Figure-5.

Conclusion and Discussion

The biophysics of radiative transfer in a soil-vegetation-atmosphere (SVA) system is very much important in understanding the crop production efficiency and success in a natural agricultural vegetation growing system. Proper and close intervention and monitoring activities over such area involving important participating parameters is thus a crucial issue to be observed in evaluating the efficacy of such system. Food security application is an important issue in the context of climate change phenomena exerting pressure on the agricultural crop production system particularly with demographic explosion the world over. The urgency for a precision agriculture system has been recognized as an area of increasing importance and care. Spectral reflectance measurements have been carried out over Togor, Rongon, Hibiscus, Jhau canopy as well as grass land. Biophysical parameters were measured in parallel to Spectral reflectance. Spectral Reflectance correlates linearly with chlorophyll content at different wavelength region. NDVI has negative correlation with reflectance at 485nm and 660nm wavelength and positive correlation with reflectance at 830nm wavelength. There is only a negative correlation of Spectral reflectance with solar irradiance at 830nm wavelength region. Lot of work needs to be done especially in the correlation of Spectral reflectance with solar irradiance at 485nm, 560 nm, 660 nm and 1650 nm wavelength. This reflectance and biophysical parameters are highly dependent on structure and nature of the canopy.

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