Spatial Techniques for Assessing Favorable Topographic Conditions for Rubber Plantation

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Abstract

Rubber (*Hevea brasiliensis*) is a valuable cash crop and the primary source of natural rubber. Ecophysiological and topographical factors are main governing parameters in sustainable cultivation. Present study focused on application of satellite Remote Sensing (RS) and Geographic Information techniques to determine suitable topographic factors for high productivity of rubber.

Dartonfield Estate in Kalutara, Sri Lanka was selected for the investigation. QuickBird high resolution satellite images were used for RS analysis and 1:10000 scale topographic maps including field observations were used for modeling of topographic characteristics. Chlorophyll content of rubber leaves was measured using SPAD-502 Chlorophyll meter. Relationship between total leaf chlorophyll content and NDVI values was determined, and it was correlated with yield data.

NDVI vs Chlorophyll showed positive correlation ($r^2 > 0.5$). Chlorophyll content of rubber leaves was slightly lower on top of the ridges while higher on the southwestern slopes. The highest latex yield was on the high elevated ridges while the lowest towards the bottom of the southwestern slopes. Therefore, hilly grounds are more suitable for rubber cultivation than flat ground valley bottom.

Key words: Remote Sensing, NDVI, chlorophyll, latex yield.

1. Introduction

Rubber (*Hevea brasiliensis*) belongs to the family Euphorbiaceae is native to rain forests in the Amazon region of South America. Rubber is one of main cash crops in the world and is a valuable source of natural rubber. Rubber is widely grown for its latex, and tree can be exploited about 30 years from the commencement of tapping. Other significant benefits from rubber plantations are timber and potential to value of its carbon sequestering capacity through carbon trading.

Rubber is a tropical tree and the tree is more adaptable to climatic conditions in a large range between 10^0 S and 10^0 N latitude (Strahler, 1969; Brandshaw, 1977). Rubber is considered as a commercial plantation crop in many parts of South American, African and Asian continents, which are located in tropical region (Wijayakumar *et al*., 2000). Natural rubber producing Asian countries cater to around 95 per cent of the world demand for natural rubber. Major rubber producing countries in the Asian region are Thailand, Indonesia, Malayasia, India, Vietnam, China, Sri Lanka etc.

Well distributed rainfall throughout the year within the range of 1650-3000 mm is reported as the suitable rainfall for the rubber cultivation. The temperature in the range of 23 – 28^{o}C, altitude less than 200 m above sea level (Yogaratnam, 2001) high relative humidity (80%) and radiation level (2000

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h/year) are ideal climatic and physical conditions for growing and yielding of rubber (Pushpadas and Karthikakutty, 1980; Rao and Vijayakumar, 1992). Well-drained soil with good aeration, structure and water holding capacity is found as favourable soil conditions for rubber cultivation (Yogaratnam, 2001).

Multiple factors affecting rubber latex yield are geography/topographic characteristics, type of clone, age, diseases, climatic factors, tapping methods, agronomic factors etc. When selecting a suitable land for planting rubber for sustainable plantation, interactions among above factors should be taken into consideration because they all play a vital role in latex production. High land productivity is a prime important factor in establishing a commercial cultivation of rubber. With the increasing demand for natural rubber there was a need for expansion of rubber cultivation to new potential sites in non-traditional areas. In this context understanding the ecophysiological principles governing the latex productivity (Rodrigo, 2007) and topographical characteristics is vital to assess the sustainability. Photosynthetic rates and water use efficiency are greater in high-yielding clones. The spatial and temporal efficiency by which plants acquire growth resources determine the overall productivity of the rubber crop. Thus, application of spatial techniques along with remote sensing information to characterize topographic features of a terrain is an effective and efficient method. These techniques can be used to model spatial and temporal variation of topographic and other ecophysiological factors.

Rubber information system including spatial and temporal distribution of rubber cultivation in India has been developed using Remote Sensing and GIS (Rao *et al*., 2006; Lallanthanga *et al*., 2014). Feasibility of mapping rubber growing area distribution using Remote Sensing technique has been explored (Menon, 1991; Rao, 1991). Application of modern tools, Remote Sensing, GIS and GPS to study soils in relation to rubber plantations in Kanyakumar district, India, has been reported by Shankar *et al*. (2008).

Photosynthesis is the primary source of energy input for most terrestrial and aquatic ecosystems. The amount of solar radiation absorbed by a leaf is a function of the photosynthetic pigment. Thus the chlorophyll content is directly related to the photosynthetic potential and primary production (Curran *et al*., 1990; Filella *et al*., 1995). Chlorophyll indicates an indirect estimation of the nutrient status of the plant because much of leaf nitrogen is incorporated in chlorophyll (Filellia *et al*., 1995; Moran *et al*., 2000). Also chlorophyll content of rubber leaves is an indication of healthiness and the production of a plantation.

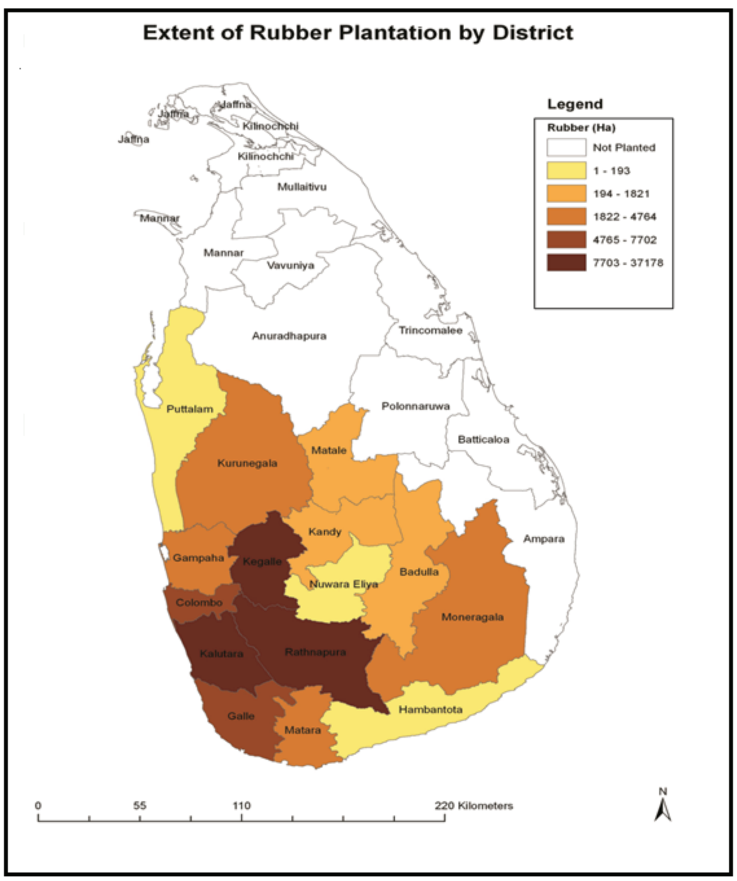

Figure 1. Rubber Plantation Distribution Map of Sri Lanka (Source: Central Bank Annual Report 2014).

1.1 Rubber plantation in Sri Lanka

Rubber plantation sites in Sri Lanka were used for the assessment in this study. Rubber is one of major export crops in Sri Lanka and the rubber industry contributes significantly to the economic growth of the country. Total rubber extent in Sri Lanka was recorded as approximately 133,400 ha at the end of 2014 and its contribution to the world market was 1.8 % (Anon, 2014). Rubber plantations in Sri Lankan lie mostly in the Wet Zone (WZ) of the country and certain regions in the Intermediate Zone (IZ). Administrative district-wise, a considerable extent of rubber growing areas are in Kegalle, Kalutara, Ratnapura, Gampaha, Colombo, Matara and Galle districts in WZ, and Kurunegala, Matale and Moneragala districts in IZ (Figure 1)

Though, rubber plantation in Sri Lanka is being extended into many parts, main controlling factors for sustainable cultivation have not been properly studied, specially climatological and topographical factors. These factors are studied conventionally using *in situ* measurements and observations, but it is time consuming and expensive. Use of Satellite Remote Sensing (RS) and Geographic Information System (GIS) techniques to determine suitable topographic characteristics for high productivity of rubber plantations is the main objective of the present study.

2. Materials and Methods

Experiments were designed to develop a model on most suitable terrains for the rubber plantation in Sri Lanka.

2.1 Study area

In this study, Dartonfield Estate in Kaluthara district managed by Rubber Research Institute of Sri Lanka in Kaluthara district was used for the analysis. Kaluthara falls in the western part of the island and is within the wet climatic zone of Sri Lanka. The district receives over 5000 mm average annual rainfall, and mostly rain from south-western monsoon

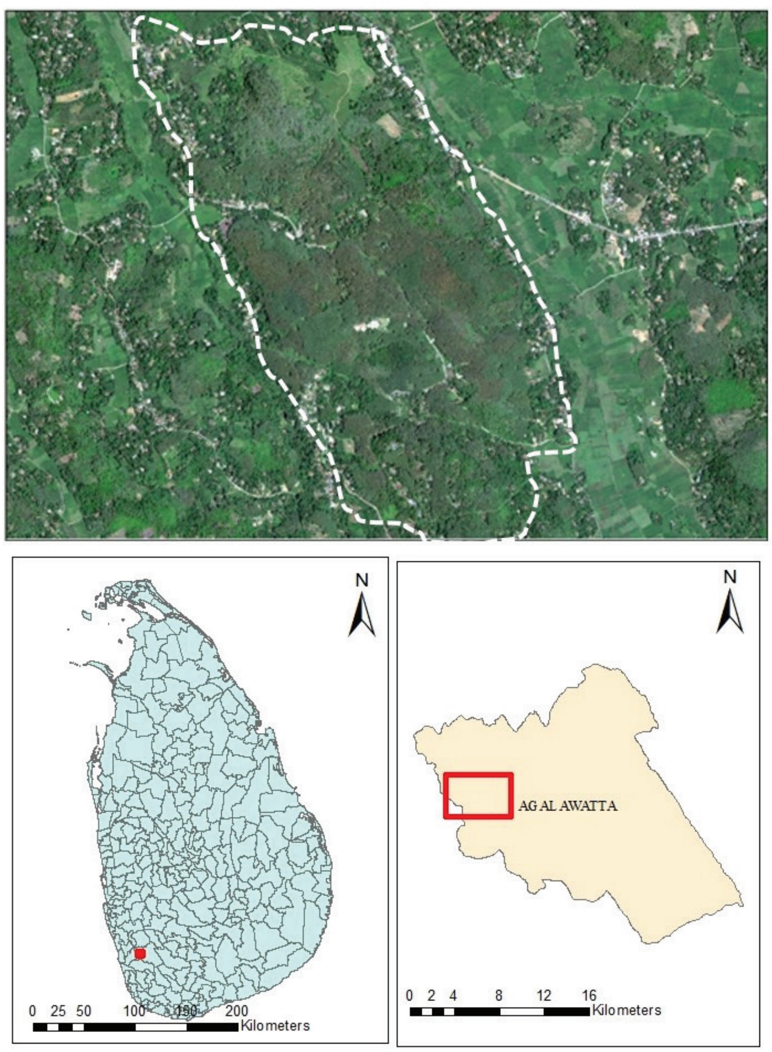

Figure 2. Map of the study area (Dartonfield Estate, Agalawatta).

during May- September and some rain during October-December period from inter-monsoon. The study area falls in fairly low elevated terrain in Sri Lanka having elevation range from 50 m to 100 m (from mean sea level). However, the area is characterized by presenting elongated ridge and valley topography with shallow to steep slopes (Figures 2).

2.2 Data Used

QuickBird high resolution satellite images were used for RS analysis and 1:10000 scale topographic maps and field observations were used for modeling the topographic characteristics. QuickBird images were used to determine Normalized Difference Vegetation Index (NDVI).

As one of the key indicators for healthiness of rubber plantation, chlorophyll content of rubber leaves was measured using SPAD-502 Chlorophyll meter. Standard extraction technique developed by Arnon (1949) was used to quantify total chlorophyll content of the rubber leaf.

Ground observations and chlorophyll data along with RS data were analysed using GIS and spatial statistical methods to determine most suitable terrains for the rubber plantation. Relationship between total leaf chlorophyll content and NDVI values was determined and yield parameters were correlated with chlorophyll content and NDVI values.

3. Results

3.1 Topographic Characteristics and NDVI of Agalawatta (Dartonfield Estate)

The rubber plantation is mostly confined to ridge areas having steep slopes. Slope direction or slope aspect map showed most of the slopes face to west and south directions. NDVI map which represents biomass content of the ground showed clear variation in different terrains having different topographic characteristics regardless of clone and other factors of the plantation. NDVI values were higher in most of the western slopes areas, and it was relatively lower on top of the ridge as well as valley bottom with flat ground (Figure 3).

Since most of the ridges in the area elongated into the NW-SE direction, the higher NDVI values were displayed on slopes facing to the SW and the South. Low elevated flat ground areas with less vegetation where roads and buildings occupy showed low NDVI values mostly minus values. It has direct relation to chlorophyll content of leaves. Therefore, yield and healthiness of rubber would be a factor of NDVI.

3.2 Cross-Sectional Analysis of Chlorophyll in a Ridge

The section was selected to perpendicular to the elongated strike ridge which is trending the NW-SE direction. Thus the cross section measurements were taken along a line falls into the NE-SW direction. Five samples were analyzed at each point of the slope (1 to 5). At the highest elevation (measured) chlorophyll content was slightly lower than that of the southwestern slopes of the upper regions. Trees grown in the southwestern slopes contained relatively higher chlorophyll concentration than the northeastern slopes. Chlorophyll content showed slight variation with the elevation while marked variation with the slope direction (Figure 4).

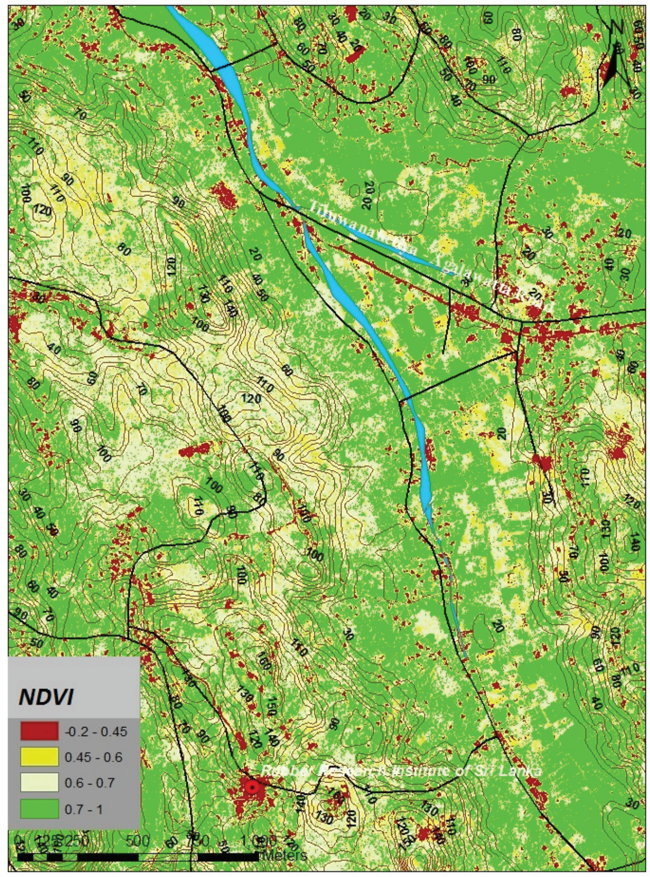

Figure 3. Chlorophyll Map with contour of Dartonfield rubber plantation.

In-situ chlorophyll analysis and NDVI analysis in the site were correlated at different elevations and slopes. The results reveal that there is a positive correlation ($r^2 = 0.53$) between NDVI and total chlorophyll content of rubber leaves regardless of the elevation and slope conditions (Figures 5).

Yield (YPH) of trees located in different slopes and sun directions varied with elevation and slope direction. Highest YPH was obtained from trees located on the high elevated ridge tops. Comparatively lower YPH was recorded for the trees grown on slopes facing the southwestern direction. Also YPH of trees grown on the southwestern slope was not comparable to the northeastern slope (Figure 6).

4. Discussion and Conclusions

Chlorophyll is the key component in photosynthetic process and the chlorophyll concentration of a leaf provides valuable

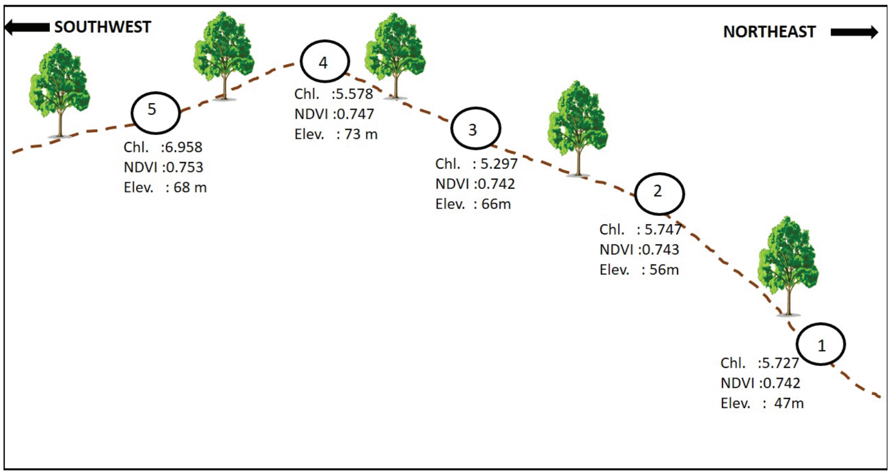

Figure 4. Cross-Sectional View showing chlorophyll (mg/g tissue), NDVI value with slope direction and the elevation (Points labeled as 1-5 refer to DP1-DP5 locations)

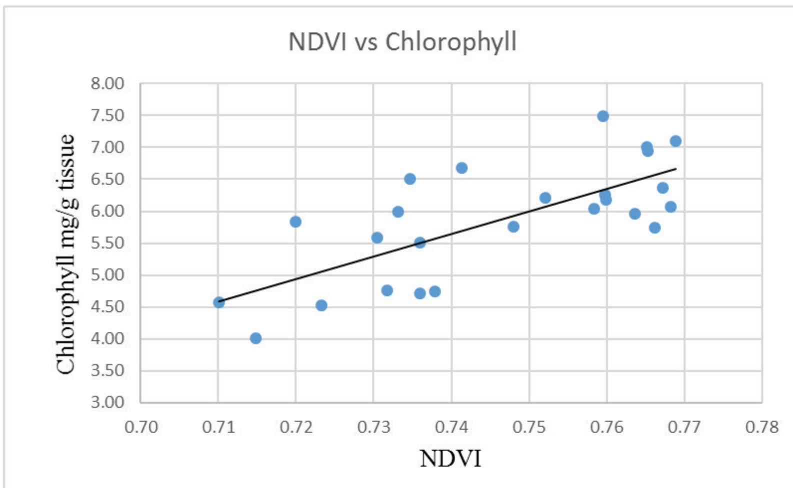

Figure 5. Relationship between NDVI and total leaf chlorophyll content at Dartonfield Estate.

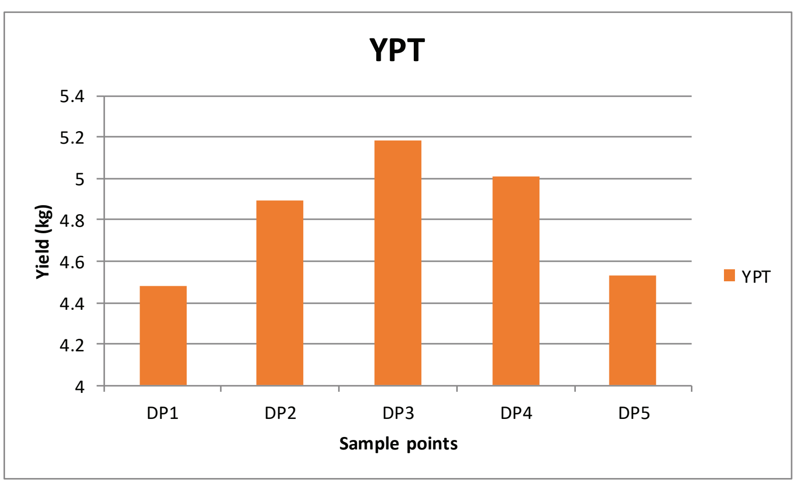

Figure 6. YPT at different elevation and slopes. YPT (Yield per tree per year)

information on photosynthetic potential and physiological status of a plant. The accessible NDVI value could be used as an indicator for chlorophyll level in the plantation. The canopy photosynthesis of rubber is a determining factor of productivity, and that is naturally optimized by partitioning of photosynthetic capacity possessing the leaves with the potential of capturing light under the natural light conditions (Gunasekera *et al*., 2013). Further, growth is directly related to the amount of radiation intercepted by a canopy (Monteith *et al*., 1991). Light is an important factor that strongly influences leaf anatomy and total chlorophyll content. The observed variation in leaf chlorophyll content in the plantation indicates the photosynthetic capacity and productivity of trees growing in different elevation and slopes. Since the sampling sites are located in the northern hemisphere of earth, the sun exposure towards the eastern slopes is greater than the westwards slopes. However, Wang (2014) reported that when light intensity increases the total chlorophyll content decreases slightly. Shade plants usually have higher chlorophyll concentration per leaf weight and higher proportion of chlorophyll b relative to chlorophyll a. This feature is an evident for the adaptation to increase absorption of the limited red light in forest shade (Boardman, 1977).

Shade leave have a higher chlorophyll concentration per unit of fresh mass than sun leaves, because a greater quantity of chlorophyll is associated with antennae molecules in shade leaves (Anderson and Osmond, 1987; Barath *et al*., 2001 and Evans and Pooter, 2001). Highly pigmented areas in the western slope in NDVI map indicate the adaptability of trees to the light limitation. Highly pigmented leaves show higher light absorption efficiency per unit of leaf biomass, which is an adaptation of plants to maintain a better carbon balance under light limitation (Enriquez and Sand-Jensen, 2003). Present study is based on remote sensing techniques using high resolution satellite images with well-defined indexes such as NDVI for Chlorophyll studies (Gamon *et al*., 1995; Penuelas and Filella, 1998). NDVI was calculated using high resolution Quikebird satellite images (used spectral bands of 940 nm -IR and 660 nm -Red) and found topographic factors affect the chlorophyll content of leaves. Slope direction, slope angle and ground elevation are major physical and natural factors that control the chlorophyll content of leaves. As there is a positive correlation among Chlorophyll content of leaves, NDVI and topographic characteristics it is further correlated to latex yield (Figure 6)

NDVI vs Chlorophyll showed positive correlation $r^2 > 0.5$ and NDVI and chlorophyll both are greater on grounds facing the westwards. Top of the ridges and the eastern slope valley bottom with flat grounds exhibited slightly lower NDVI as well as chlorophyll content. However, results reveal that slopes and hilly areas produced more yield and therefore, such grounds are more suitable for rubber cultivation than flat ground valley bottom.

Acknowledgements

We wish to thank University of Sri Jayewardenepura for providing financial assistance (Grant No. ASP/06/RE/SDI/2013/02) and Rubber Research Institute of Sri Lanka for providing facilities to carry out this research project.

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