Remote Sensing a Tool to Measure and Monitor Tea Plantations in Northeast India

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Keywords: Tea plantations, NDVI, LAI, waterlogging and biophysical status

SUMMARY

Tea yield has stagnated in Northeast India which is attributed to several factors such as old age of tea bushes, declining soil health, waterlogging and increased incidence of pests and diseases. Therefore monitoring tea using remote sensing has become a pressing need.

Understanding the effect of waterlogging, and biophysical status of the tea would help the estates to take effective measures when the need arises. Delineating waterlogged tea areas showed that waterlogging was caused by blocking of natural drainage by eutrophication, built up areas and siltation and this could be well monitored through remote sensing. Establishing an empirical equation between MODIS derived NDVI and LAI showed that LAI in tea had significant and linear relationship with NDVI. However, the NDVI observation at different time periods alone could not explain much variance in tea leaf yield.

The study took into consideration different methods and approaches that could fit well in monitoring and quantifying tea plantations from time to time. It also indicated that the tea area problems can be easily monitored by using a GIS platform.

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1. INTRODUCTION

Tea is an evergreen shrub from the genus *Camellia* that includes some 82 species (Banerjee, 1992). Of all the species, tea is the most important both commercially and taxonomically and is cultivated to produce a stimulant brew. In India, *Camellia sinensis* var. *assamica* is most widely used. Tea is a leading cash crop in world agriculture with its production increasing from 850 million kg during the year 2000 – 2003 to 980 million kg 2004 – 2007 (Dutta et al., 2010). Tea is indigenous to India and is an area where the country can take a lot of pride. This is mainly because of its pre-eminence as a foreign exchange earner. Stagnation in tea production and decline in tea quality are seen as major problems by the tea industry which is attributed to several factors such as old age of tea plantations, waterlogging, declining soil health and increased incidence of pests and diseases (Dutta et al., 2008). Tea is affected by a plethora of factors ranging from genotype, environment and management (Dutta et al., 2010).

The monsoonal climate of Northeastern India is accompanied by alternate wet and dry seasons giving a unique opportunity to have too much and too little water. Of late, large tea plantations of about 350,000 ha supported by this region have become susceptible to continued water logging, droughts, soil erosion etc. in certain areas. Due to flowing of water through the catchments, the drainage problems have to be addressed on the basis of a watershed which has a multidimensional issues and priorities (Bordoloi et al., 2006). Topographic information at the catchment level including the existing natural drainage network is very essential. Strong and accurate diagnostic tools are also required for identifying the exact nature of drainage problems and the geographic changes that have taken over time (Bhagat et al., 2007). With the increasing frequency of expansion of tea cultivation, low lying areas for growing of thatch, bamboo, fuel plants or paddy cultivation are now covered by tea plantations. Instead of facing the high water table problems in these new expansions, it is causing siltation in the natural drainage system in the recent years. Although riparian laws forbid the blocking of the waterways, this is hardly enforced (Bordoloi, 1993). Occasional blockades of tertiary streams serving as main drainage base for the tea estates and encroachments of these streams have further deteriorated their carrying capacity. Disposal of excess water through pumping system resulted in problems to the adjoining paddy fields which are often inundated due to silting/blockage of natural drainage system. Remote sensing techniques can be a very useful tool to visualize larger areas at a time with its distinctive features and also the geomorphic changes. Use of remote sensing data on a geographic information system (GIS) platform would help store, manipulate, analyze a huge database (spatial and non-spatial) and display/reproduce the data in a more meaningful and usable manner (Bordoloi and Borbora, 1994).

The use of space-based remote sensing techniques is well established for regional and global monitoring and assessment of agricultural crops using various kinds of vegetation indices (Gallo and Flesch 1989, Carlson et al. 1990, Goward et al. 1993, Cihlar et al. 1991, Rao et al., 2007). The examination of the relationship between vegetation indices and LAI has been studied frequently over the years and had shown to be useful for yield prediction purposes (Major et al. 1990, Rudorff and Batista 1990). The NDVI is a widely used spectral transformation which is considered as a measure of plant productivity and is sensitive to vegetation parameters such as the green leaf area index, the fraction of absorbed photosynthetically active radiation and the percentage of ground surface covered by vegetation (Sellers 1985, Tucker and Sellers 1986). It has been reported by various researchers that the correlation between LAI and NDVI is not consistent and shows insensitivity, particularly in high leaf area vegetation like deciduous forest (Rondeaux et al. 1996).

The main objective of this study is to delineate waterlogged tea areas and to derive an empirical relation between tea LAI and NDVI.

1.1 Normalized Difference Vegetation Index (NDVI)

Remote sensing techniques are used for monitoring and mapping condition of earth's ecosystem. Vegetation cover is the one of most important biophysical indicator which can be estimated using vegetation indices derived from satellite images. Vegetation indices allow us to delineate the distribution of vegetation and soil based on the characteristic reflectance patterns of green vegetation. The Normalized Difference Vegetation Index (NDVI) measures the amount of green vegetation. The spectral reflectance difference between Near Infrared (NIR) and red is used to calculate NDVI. The formula can be expressed as (Jensen, 2000):

$$NDVI = \left(\frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d} \right)$$

The NDVI has been used widely in remote sensing studies since its development (Jensen, 2005). NDVI values range from -1 to +1, where higher values are for green vegetation and low values for other common surface materials. Bare soil is represented with NDVI values which are closest to 0 and water bodies are represented with negative NDVI values (Lillesand et al., 2004; Jasinski, 1990; Sader and Winne, 1992).

1.2 Leaf Area Index

Leaf Area Index (LAI) is defined as the one sided green leaf area per unit ground area in broadleaf canopies, or as the projected needle leaf area per unit ground area in needle canopies. Various destructive and non-destructive methodologies to measure LAI do exist. Non-destructive methods include hemispherical photography, sunfleck ceptometers, and other optical instruments like TRAC, LAI-2000 or LI-COR (Chen et al. 1997). The Licor LAI-2000 plant canopy analyzer was used to collect LAI data according to methods in their manual (Licor, 1992). The instrument measures how much light is attenuated at several angles as it passes through the canopy and then with internal software it calculates LAI according to Beers law (Monteith and Unsworth, 1990). The plant canopy analyzer gives the LAI values directly using the equation given below:

$$LAI = \frac{Leaf\ Area}{Sample\ Area}$$

The tea plant canopy coverage has to be considered from the satellite imagery. Both leaf area and the sample area should have the units.

$$LAI = \frac{Leaf\ Area}{Sample\, Surfce\ Area}$$

where,

$$Actual\, Coverge = \frac{Actual\, Plant\ Density}{Optimum\ Plant\ Density}$$

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out in Assam in the Northeastern region of India. The area under investigation included a) Tingrai basin of Upper Assam and b) Sonitpur district of North Bank (Fig. 1).

Tingrai basin is located at the border of Tinsukia and Dibrugarh districts of Upper Assam, India and covers an area of about 457 square kilometers between 27.20° N latitude and 95.15° E longitude. More than 35 medium and large tea gardens are situated in this area. Tingrai is a part of vast flat alluvial terrain between Brahmaputra River and Patkai hills. Tingrai River is the main drainage channel in this area. The area experiences humid monsoonal climate, with hot summers and cool winters. Average annual rainfall in the area is about 2850 mm. The major reason for selecting this as a study area was, the waterlogging becoming a serious and speedily aggravating problem in the tea growing area.

Sonitpur district is spread over an area of 5324 square kilometers on the North Bank of Brahmaputra River. The District lies between 26.30° N latitude 92.16° E longitude. Sonitpur District falls in the sub-tropical climatic region, and enjoys monsoon type of climate. Summers are hot and humid, with an average temperature of 29°C. Autumns are dry, and warm. Winters are cold and generally dry, with an average temperature of 16°C. There are seventy three tea gardens in Sonitpur district covering an area of approximately 37,555 ha (Sonitpur District Profile: National Informatics Centre, Government of India).

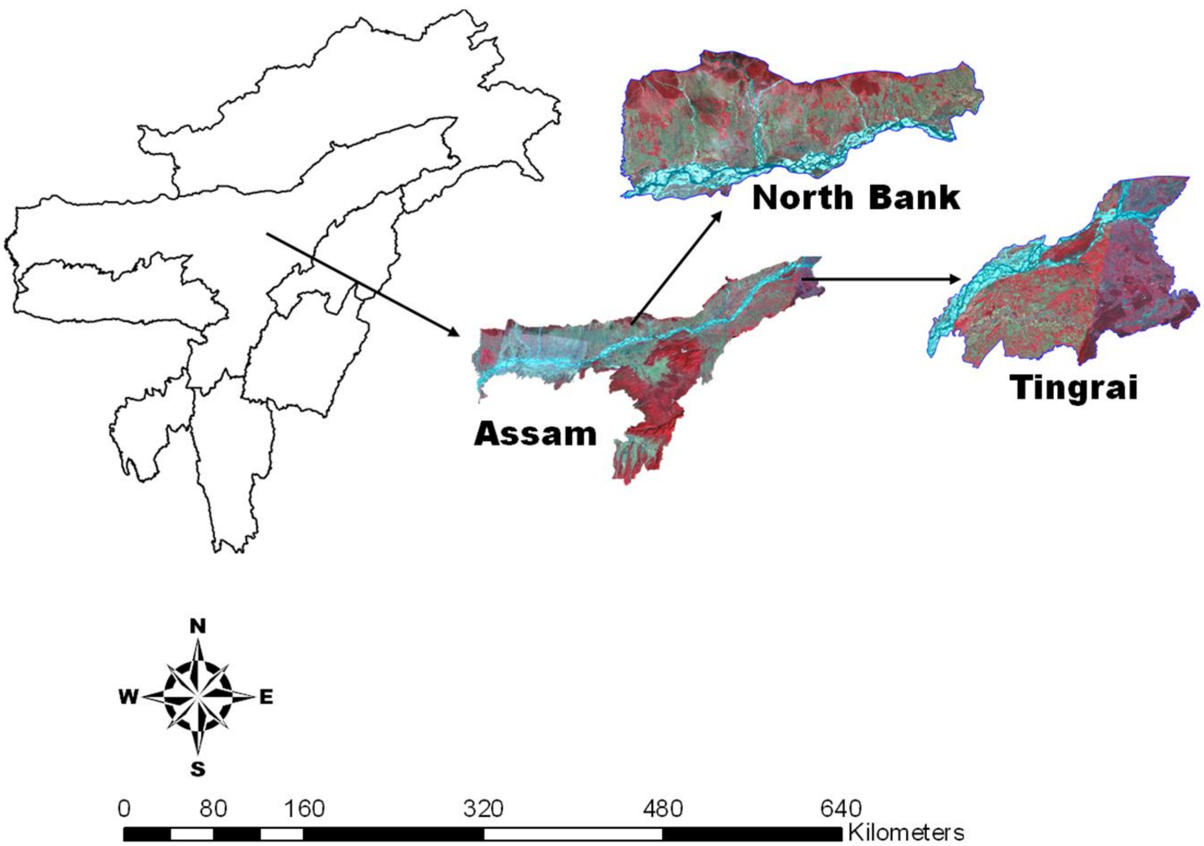

Fig. 1 Map showing the tea growing areas in Assam

2.2 Data Used

For delineation of waterlogged areas, the main sources of data was LISS IV (5.8 m resolution) mono and LISS III (23.8m resolution) geo-coded standard false colour composite (FCC) digital image of RESOURCESAT 1 (IRS P6), procured from National Remote Sensing Centre (NRSC), Hyderabad, India. The statistical data were collected from the tea estate records and Tea Research Association data files.

Similarly, to examine the relations between tea yield and remotely sensed NDVI, MODIS data for the month of April, June and August were used for the period from 2005 – 2009. This data was then used to derive the relations between tea leaf area index (LAI) and NDVI.

2.3 Methods

Image Processing

The basic spatial layers, such as administrative boundaries, contours etc. were digitized from topomaps obtained from survey of India (SOI) at 1:50,000 scale. The digital elevation model (DEM) was generated from the interpolation of contour lines and spot heights. The LISS IV mono image was geo-referenced with LISS III FCC geo-coded image. Using 'resolution merging' technique, supervised classification was done and the landuse/landcover map was generated. Geo-morphological map was generated from merged LISS III and LISS IV mono images and incorporating field information collected from the field. The drainage maps were generated by on-screen digitization of the images and extracting the Survey of India drainage system, which was later superimposed to identify change detection. Classification was done using both supervised and unsupervised techniques. In Tingrai basin, a ground survey was conducted using area frame sampling method to verify and improve classification. Field data collection was aided by GPS to locate the ground coordinates. Information on vegetation, geomorphologic, soil and topographic parameters were also collected. The information collected during ground truthing has helped in post processing of the classified images, done to improve and refine the classification. About 10 per cent of the total sample area was randomly selected for accuracy assessment while the overall accuracy was 90 per cent. Final maps were generated on the basis of pre-field assessment and interpretation, field investigation and available secondary data. Both visual and digital approaches were conjunctively used for the finalization of maps.

Further an empirical relationship between NDVI – LAI were developed to observe the variability which in turn will help in yield prediction. A year wise correlation was developed between tea leaf yields and MODIS based NDVI of the tea estate during different months.

3. RESULTS

3.1 Delineation of waterlogged tea areas

The two geomorphic units of the area are younger alluvial plain and older alluvial plain. The younger alluvial plain consists of cultivated fields and settlements. The older alluvial plains are situated comparatively at a higher elevation and all the tea estates are situated in this unit. Land cover classes were delineated which includes tea areas with estate boundaries, built up lands, agricultural areas, forests, small vegetation, swampy areas, barren areas and water bodies. The spatial coverage showed that 27.78% (127.13 sq km) of the area is under tea gardens. Tea gardens are generally situated at higher elevation than the agricultural lands. But at few places the reverse is true. It was observed that these are the places where the flooding problem is more prominent.

When the drainage layers were extracted from the SOI map of 1970 and satellite image of 2004, it appeared that most of the drainage in the SOI map has become extinct in the satellite image (Fig. 2). When the field data was correlated with the drainage maps, it showed that this is happening because of the eutrophication and man-made bunds, besides several new sub-divisions coming up as built up areas. This is the major cause of floods in the region which was due to obstruction of natural flow of water. Dried drainage networks seen in the image are also blocked by this problem and their natural flow is obstructed. Flood and water logging problems in the Tingrai area are largely caused due to hindrance of free flow of water through natural channels. Some of the channels have become extinct over the years since no water is flowing, more so because some were diverted by the estate authorities.

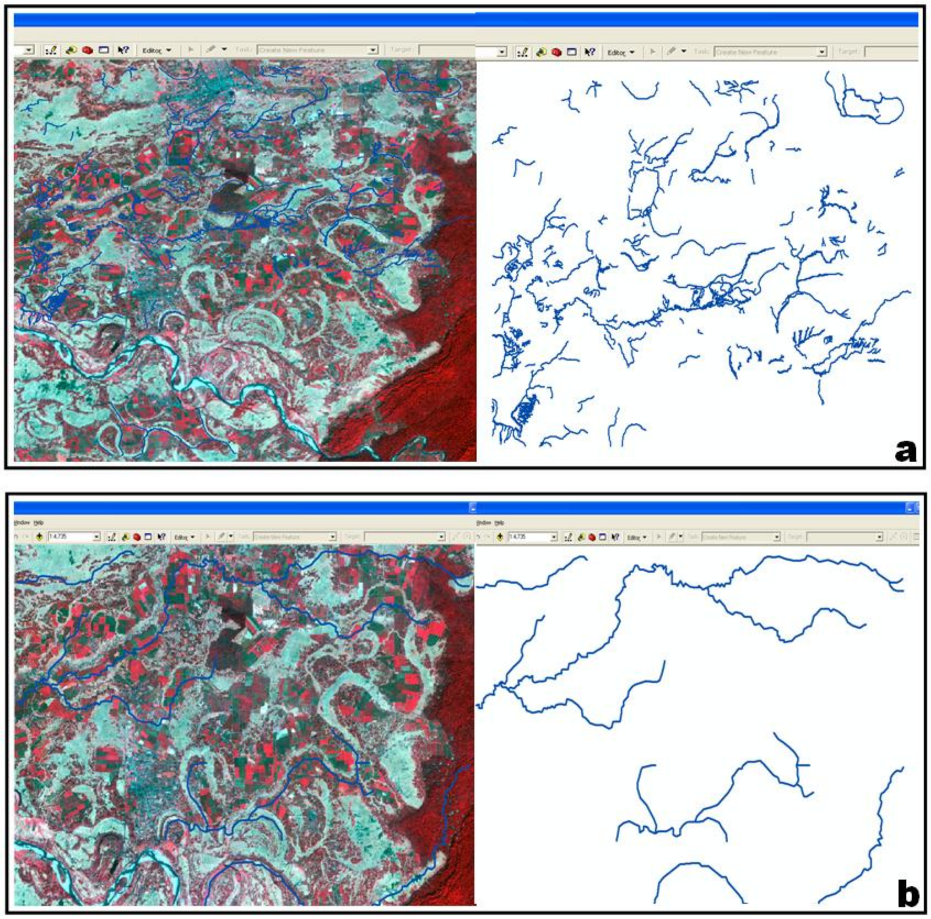

Fig. 2 Maps showing the drainage situation in Tingrai Basin (a.) 1970 and (b.) 2004

3.2 Yield Estimation

NDVI was generated for tea areas from MODIS images using 3 x 3 pixel extraction methods. The LAI – NDVI values were then plotted in the scatter plot and linearly regressed. From the analysis it was observed that there exist a strong linear relationship between LAI and MODIS based NDVI. For the yield estimation the MODIS LAI image for August and MODIS NDVI image for April, June and August from 2005 – 2009 were used. The mean NDVI for all the MODIS images were extracted using the area weighted average or zonal attribute.

3.3 LAI – NDVI Relationship

MODIS derived NDVI image was generated for the tea estate areas and the NDVI values were extracted using 3 x 3 kernels for extracting the pixels. The LAI – NDVI values were plotted and linearly regressed (Fig. 3). From the analysis it was observed that there exist a strong linear relationship between LAI and MODIS based NDVI with an R^2 value of 0.699. Thus it could be inferred that MODIS derived NDVI can approximately provide information on leaf area index for tea.

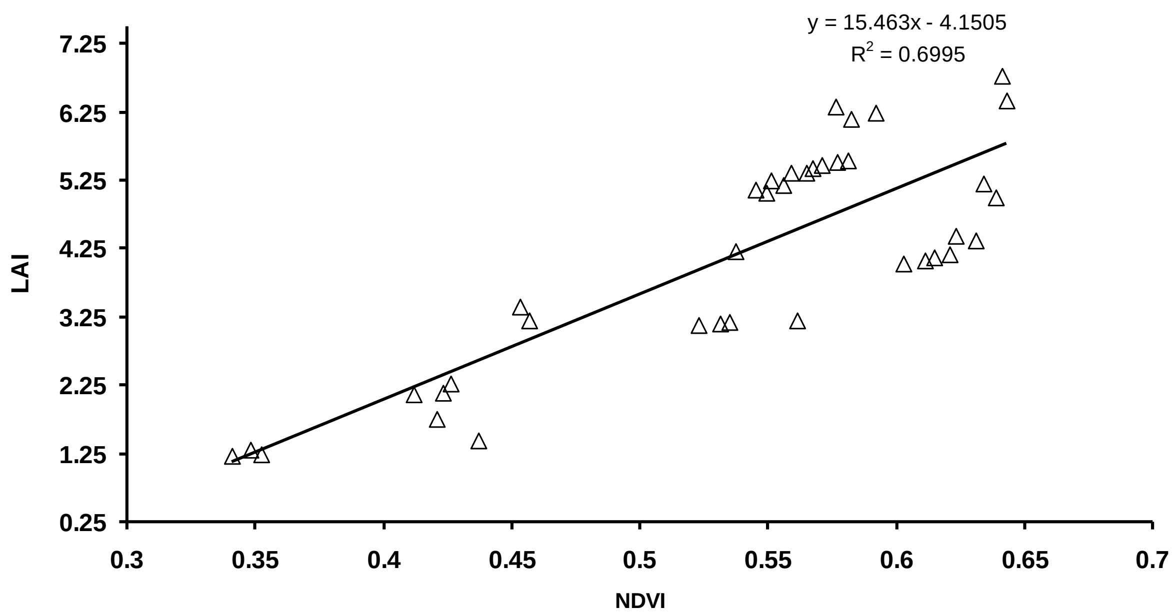

Fig. 3 LAI - NDVI Relationship

3.4 Relation between Tea Leaf Yield and MODIS NDVI

Correlation analysis was carried out between area weighted averaged NDVI of tea for selected tea estate with their tea leaf yield for different years (2005 – 2009). Results showed that correlation is positive and significant irrespective of month of the NDVI over the years (Table 1). Tea leaf yield was found significantly related to NDVI at 95% level of significance during 2006, 2007 and 2009 while during April, 2005 and June and August, 2008, correlation is positive at 1% level of significance.

Table 1 Year wise correlation between tea leaf yield and MODIS based NDVI of tea estates during different months

Year	NDVI (April)	NDVI (June)	NDVI (August)
2005	0.425**	0.441	0.432
2006	0.635*	0.672*	0.661*
2007	0.643*	0.578*	0.592*
2008	0.521	0.527**	0.545**
2009	0.521*	0.545*	0.563*

4. DISCUSSION

Although the water requirements of the tea plant is high, pore spaces should never get saturated or waterlogged as this is harmful to plant growth (Kamau, 2008). Tea plant is very sensitive to waterlogging which impair the growth and productivity of the plantation, give rise to secondary root disease – violet root rot under prolong waterlogging which culminates in crop failure if ameliorative measures are not undertaken timely (Bordoloi, 2006). Various researchers have reported the potential of optical and microwave remote sensing for waterlogging assessment (Agbu et al. 1990; Singh and Srivastav 1990; Choubay, 1997). Very few studies have used digital classification of raw satellite data for mapping surface waterlogging areas (Saha et al. 1990, Joshi and Sahai 1993, Vincent et al. 1996, Pulido et al. 1998). However, the mapping of waterlogging areas by the classification of raw satellite data has severe limitations when there is perennial vegetation cover. In severely affected areas, total crop failure may result in bare soil patches; retardation of early crop development, resulting in a mixture of thin crop and water-tolerant weeds (Rao et al., 2007). Moderately affected crop may result in yellowing or reddening of the old leaves, and failure to develop tillers, resulting in a thinner crop stand. The spectral reflectance from waterlogged crop pixels would be expected to contain a decreased contribution from the crop and an increased contribution from soil and weeds. In our study, it has been observed that extinction of natural drainage has resulted in waterlogging. The blocking is done by eutrophication and construction of man-made bunds. It was observed that majority of the flood and waterlogging problems are created largely due to hindrance of free flow of water through natural channels. Also some of the channels have become extinct over the years since no water is flowing, more so because some were diverted by the estate authorities.

Understanding the spectral characteristics of tea plantation is very important for monitoring the growth of plants and estimating tea-yield using remote sensing methods (Rajapakse et al., 2002). Leaf Area Index (LAI) is one of the key factors, useful in crop growth models that may be derived from optical remote sensing data. LAI is the leaf area per unit area of soil surface (Kvet and Marshall 1971). LAI during the growing season is important in crop growth modelling and crop reflectance modelling. Gong et al., 1995 attempted to estimate the LAI of coniferous forests using Compact Airborne Spectrophotometer Image (CASI) data by establishing a relationship between forest LAI and the NDVI. To test whether MODIS derived NDVI is related to LAI, an empirical equation was established which shows that LAI in tea had a significant and linear relationship with NDVI (R^2=0.669). This study further showed that MODIS based NDVI during April, June and August was significantly correlated to tea leaf yield at estate level. However it was found that NDVI observation at different time period alone could not explained much variance in tea leaf yield.

Remote sensing images and relevant ground truth could contribute to assess, analyze, monitor and model the characteristics of tea bush growth. To achieve timely and accurate information on the status of crops, an up-to-date crop monitoring system may provide accurate information. The earlier and more reliable the information, the greater is the value. Remote sensing offers an efficient and reliable means of collecting the information required, in order to map tea type and acreage and also the structure information on the health of the plantations. As the spectral reflectance of a tea field always varies with respect to the phenology, stage type and crop health, these could well be monitored and measured using the multispectral sensors and to detect stress associated with moisture deficiencies, insects, fungal and weed infestations and to take effective measures. Monitoring using remotely sensed images would further help tea planters to identify areas within an estate which are experiencing difficulties, in order to apply, for instance, the correct type and amount of fertilizer, pesticide or herbicide. Using this approach, the planter will not only improve the productivity but will also reduce input costs and minimizes environmental impacts.

5. CONCLUSIONS

From this study it was concluded that substantial agronomic monitoring is required to stimulate the tea sector in North East India. This study has revealed the scope of monitoring the growth and management of tea canopies using remote sensing. More specifically we conclude that:

a. This study indicated that the tea area problems in the North Eastern India can be monitored by using a GIS platform. Major problem of water logging in tea areas could be monitored through remote sensing. Blocking of natural drainage channels can be overcome by clearing the blocked drainage channels through governmental efforts and planter's participation.
b. An empirical equation could be established using MODIS derived NDVI and LAI. Although strong positive correlation exist between tea yield and NDVI but NDVI during the different time periods alone could not explain much variations in tea yield.

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BIOGRAPHICAL NOTES

Rishiraj Dutta is a PhD student currently pursuing his doctoral studies from the Department of Earth Observation Science, Faculty of Geoinformation Science and Earth Observation, University of Twente, The Netherlands. His topic of research is "Image Mining for Monitoring Tea Replantation and Assessing Environmental Factors Influencing Tea Quality." His PhD is a joint programme between University of Twente and Tea Research Association, Assam, India.

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