Teak Plantation Phenology Changes and its Relationships to Climate Variability in Lampang Province, North of Thailand

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***Abstract--*Vegetation phenology is sensitive to climate variability, and understanding changes in phenology are necessary to infer the response of forest towards climatic variability. In this study, time series of Normalized Difference Vegetation Index (NDVI) extracted from Moderate Resolution Imaging Spectroradiometer (MODIS) from 2009 to 2012 was used to investigate changes of teak plantation phenology in Lampang Province. The NDVI was validated by Leaf Area Index (LAI) and the negative logarithm of the ratio of daily downward solar radiation on the forest floor to that above the canopy (NLR).**

The results show that NDVI was significantly correlated with LAI (r=0.81), and NLR (r=0.77). Analysis from phenology metrics shows that length of growing season ranged between 264–324 days, starting from March to May and ending in January to March of the following year. In 2010, the starting of season was delayed and the length of season was shorter than other years. NDVI was negatively correlated to maximum temperature (r = -0.85, p<0.0001), whereas positively correlated to precipitation (r=0.51, p<0.0001) during the period from April to May. During the end of season (October to December), NDVI had significant and positive relationship with minimum temperature and precipitation (r=0.81, r=0.64), respectively.

This study demonstrates that NDVI extracted from satellite is able to capture the teak plantation phenology and provide spatial and temporal information for long term monitoring. The significant correlation between NDVI and climate factors in this study implies that future variability in meteorological variables under climate change would affect to forest ecosystem.

Keywords: climate variability, phenology, teak plantation, NDVI.

I. INTRODUCTION

Teak is one of the most well known timbers of the world. Teak normally grows within a latitudinal range of 16^0 to 20^0N and a longitudinal range of 97^0 to 101^0E. Teak forest is found in mixed deciduous forest throughout the North of Thailand and it covers about 25,000 km^2 [1]. The optimum condition for growing teak is the range of annual rainfall approximately 1,250-1,650 mm with the marked dry season of 3-5 months. Teak seedlings grown under the high constant soil moisture (near the saturating point) for eight weeks were about five times greater, in term of dry matter production, than those grown under the severe soil moisture stress (near the wilting point) [1]. The critical maximum and minimum day/night temperature for growth and development of teak seedlings were about $36^0/31^0$ and $21^0/16^0$C, respectively [2].

According to the model projections by Gopalakrishnan *et al* [3], 30% of teak grids in India are vulnerable to climate change under both A2 and B2 scenarios (scenario A2: atmospheric CO_2 concentration reaches 740 ppm by 2085; B2 scenario: CO_2 concentration reaches 575 ppm by 2085), the future climate may not be optimal for teak at these grids due to changing of sunlight, water and CO_2. This suggests that teak plantation in Thailand may be vulnerable to changing climate. Therefore, monitoring teak plantation dynamics and understanding its relationship with climate variability is becoming important which should be considered for long-term teak plantation programs.

Vegetation phenology is the study of the timing of periodic biological events in the plant as influenced by the environment [3]. Long-term monitoring phenological on trees provide information to indicate how plants have responded to variations in climatic conditions, which links to the biodiversity and ecosystem services [4].

In Thailand, minimum and maximum temperatures have been increasing continuously during the last 60 years [5]. Extreme climate phenomena such as El Nino in 1997-1998 and 2009-2010 have become more frequent and severe. Many areas in North of Thailand were affected by drought during summer to early rainy season in year 2010 [5]. Other researches have shown that temperature extreme indices have significantly increased in Northern Thailand during 1960-2010, and climate projections indicate that summer days are expected to increase significantly in the future [6]. Annual rainfall is projected to increase by 9.65% in the future period of 2011-2099 compare to the period 1960-2010 [6]. However, the impacts of projected climate changes on the vegetation of the tropics zone, particularly Southeast Asia, are currently poorly understood [7]. Therefore, there is an urgent need to take into account such impacts in order to determining the effects of climate factors on forest phenology including teak plantation.

Satellite imagery provides consistent and repeatable measurements at a spatial and temporal scale of study vegetation dynamic [8], [9], [10]. Among remotely sensed surface parameter, Normalized Difference Vegetation Index (NDVI) has been widely used as an indicator of vegetation growth status, special density distribution and phenology [11], [9], [12], [13]. In term of forest ecosystem and biodiversity research in Thailand, there are needs to increase our understanding of how the vegetation responds to climate variability in the spatial and temporal scale. This research paper is the first step trying to fill the knowledge gap and to quantify the response of vegetation dynamics to climate variability, by using teak plantation as a case study.

II. MATERIAL AND METHODS

A. Study Area

Lampang is situated in Northern Thailand with an area of 12,534 square kilometers. Lampang locates on a plateau with the altitude of 268.80 meters above sea level (Fig. 1). In Lampang, average temperature in summer and winter is 41.5^0C and 10.5^0C, respectively. The average annual rainfall is 1,098 mm. Teak plantation is widely distributed in Lampang. Based on topography, precipitation and temperature, Lampang is the geographic representation of Thai provenances for field trials of teak genetic [14], therefore it is selected for this study.

B. Data Used

1) MODIS Data: Surface Reflectance MOD09Q1 of MODIS product providing Bands 1 (Red) and Band 2 (NIR) at 250-meter resolution and MOD09A1 at 500 meter resolution in an 8-day period were used in this study. Cloud cover is presented in MOD09Q1 images, which limits the potential of images for ground information extraction. Removing cloud and replacing cloud contaminated pixels is necessary in phenology extraction. All series of 184 images was applied with cloud removal method which developed by Hoan and Tateishi [15] to provide free cloud data sets for further analysis on teak plantation phenology.

2) Meteorological Records: Climate data used in this study was obtained for the period of 2009-2012 from Thai Meteorological Department. The 4-year variation (2009–2012) of the following climatic factors was analyzed:

- Maximum and minimum temperature: the daily maximum and minimum temperatures was averaged and aggregated for a 8-days period.
- Accumulated precipitation: the total precipitation was computed for each 8-days period.

In general the growing season of teak plantation starts in March or April and ends in January or February of following year [16], therefore whole year meteorological data was used in this study. The nearest meteorological station to study site of teak plantation in Lampang province was used for analyzing correlation between NDVI and climate variables (air temperature and precipitation).

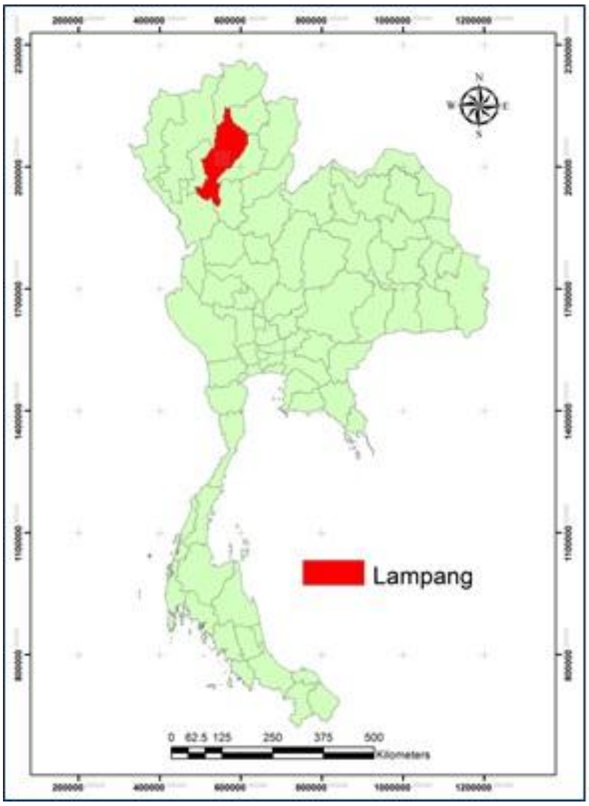

Fig. 1 Location of study area in Lampang Province

3) *Observation Data:* The observation data for validation of the NDVI pattern in this study were collected from teak plantation in Mae Mo, Lampang province, Northern Thailand (18°25'N, 99°43'E, 380 meter above sea level) by Yoshifuji et al. [16] .

Observation data were collected from previous research including the negative logarithm of the ratio of daily downward solar radiation on the forest floor to that above the canopy (NLR) and Leaf Area Index (LAI, m^2m^{-2}) [17], [18]. The collected data are daily data and in this study, they were aggrerated to 8 days temporal resolution for comparing to teak plantation NDVI (Fig. 5).

C. Methodology

1) Time Series Analysis for Phenological Metrics of Teak Plantation: At a pixel scale (250 × 250 meter), 46 points NDVI time series revealed seasonal growth of teak plantation in each year. Savitsky-Golay as discussed by Jonsson and Eklundh in TIMESAT software package was used to fit the curve of time series data following second order polynomial and to extract the following phenological metrics [19], [20], [21], [22].

- *Start of growing season* (*SOS*)*:* This is defined as the dates of leaf unfolding, this study considered SOS as a date when NDVI increases to 5% of the amplitude during the beginning period of the NDVI time series. For the series of NDVI in a given year, $NDVI_{max}$ is the maximum of NDVI and $NDVI_{min}$ is minimum of NDVI in the first half of the year. $NDVI_{start}$ was calculated as follows;

$$NDVI_{start} = NDVI_{min} + (NDVI_{max} - NDVI_{min}) \times 0.05$$

- *End of the season* (*EOS*)*:* This is defined as the dates leaf discoloration and leaf fall at the end of season. This study considered EOS as a date when NDVI decreases to 5% of the amplitude during the ending period of the NDVI time series. $NDVI_{end}$ was calculated as follows;

$$NDVI_{end} = NDVI_{min} + (NDVI_{max} - NDVI_{min}) \times 0.05$$

- *Length of the season* (*LOS*) *is the during (number of days)* from the start to the end of the season.

The results of 5% changing in NDVI value from minimum for SOS and EOS agreed to the transition date of LAI index and NLR, therefore this threshold has been applied for extracting seasonality data such as start, end of the season and the length of the season in this study.

2) *Relationship between NDVI and Climate Factors:* Daily data at meteorological station in Lampang Province were aggregated to 8 days period by calculating average for temperature and accumulation for precipitation. Base on the distribution of data, the non-parametric Spearman was applied to check the correlation coefficient between NDVI and climate factors [23].

III. RESULTS AND DISCUSSION

A. NDVI Time Series of Teak Plantation

The variation of NDVI, precipitation, minimum and maximum temperature at

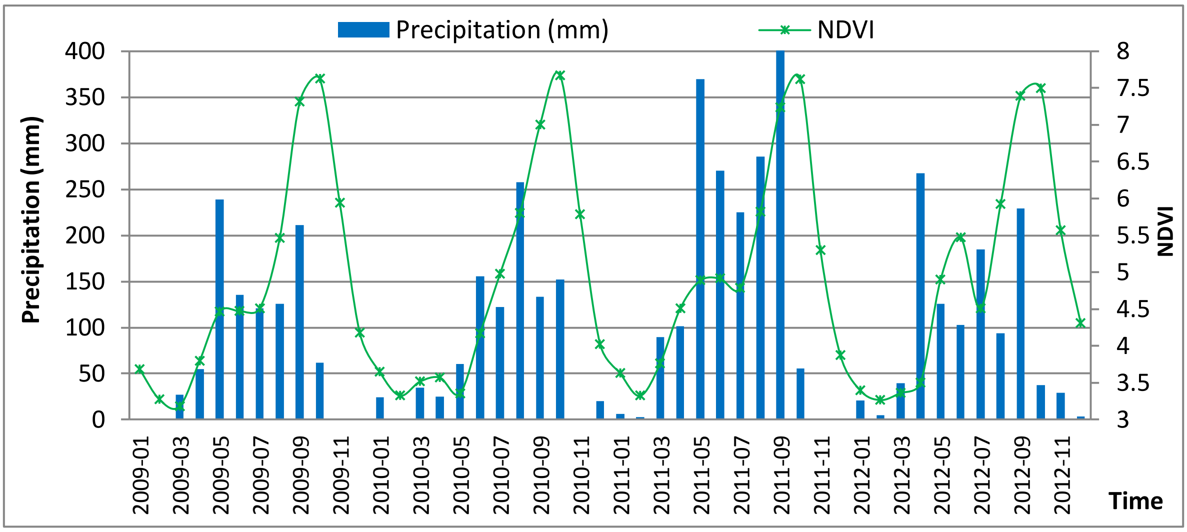

Fig. 2 Time series of NDVI (green line) and precipitation (blue bar) of Teak plantation period 2009-2012

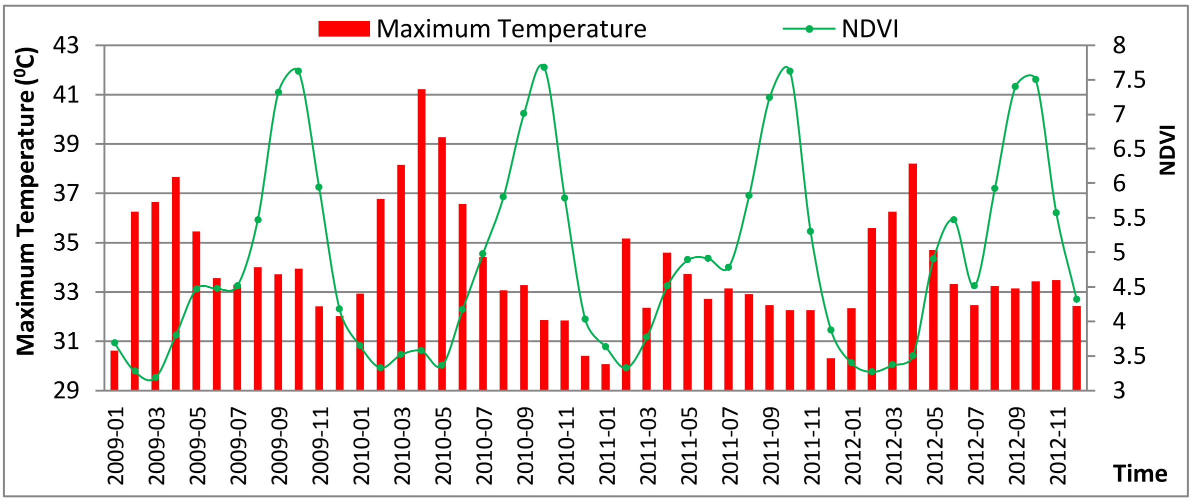

Fig. 3 Time series of NDVI (green line) and maximum temperature (red bar) of Teak plantation period 2009-2012

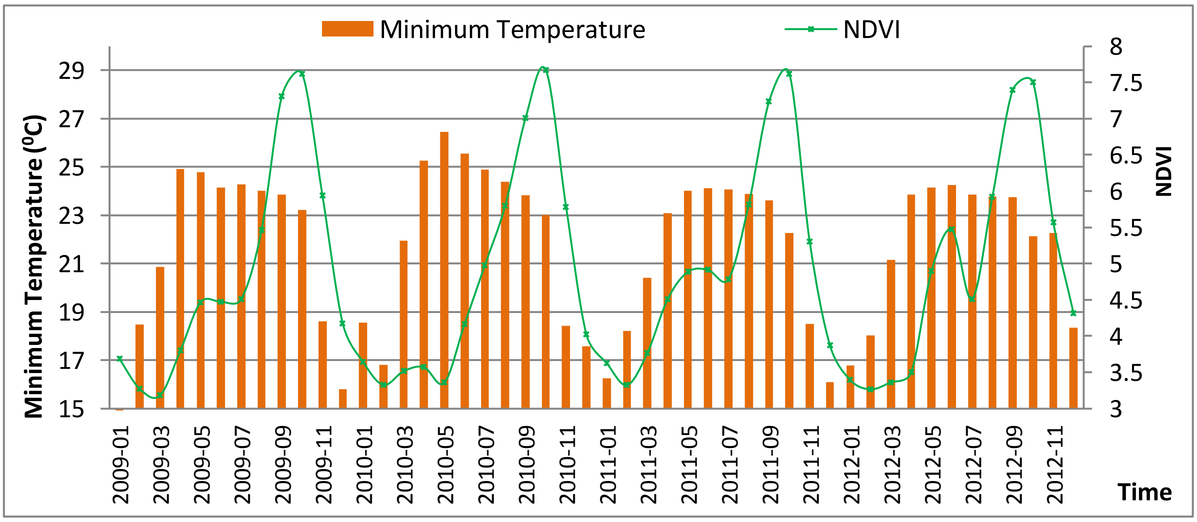

Fig. 4 Time series of NDVI (green line) and minimum temperature (orange bar) of Teak plantation period 2009-2012

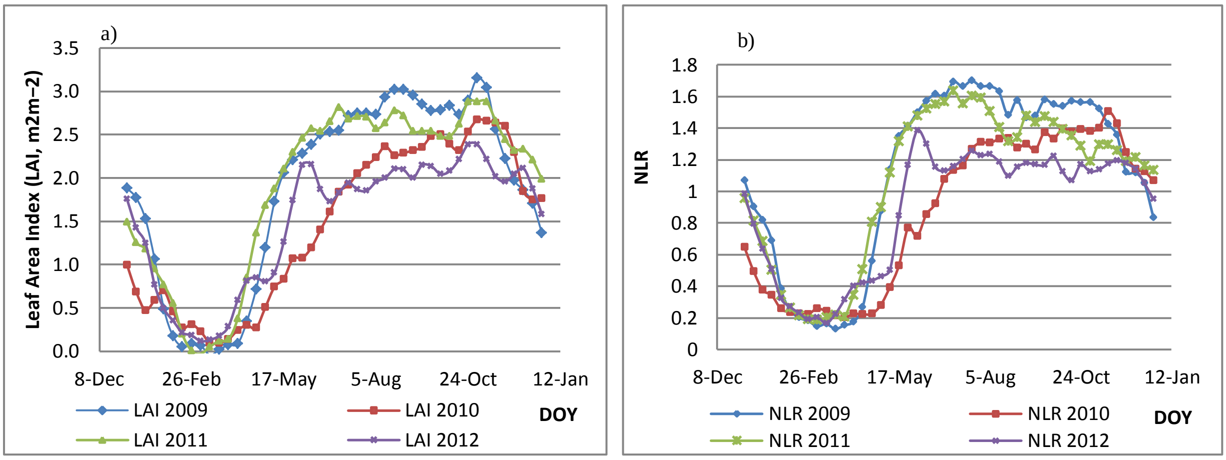

Fig. 5 The observation data of teak forest a) Leaf Area Index (LAI, m^2m^{-2}); b) the negative logarithm of the ratio of daily downward solar radiation on the forest fl oor to that above the canopy (NLR)

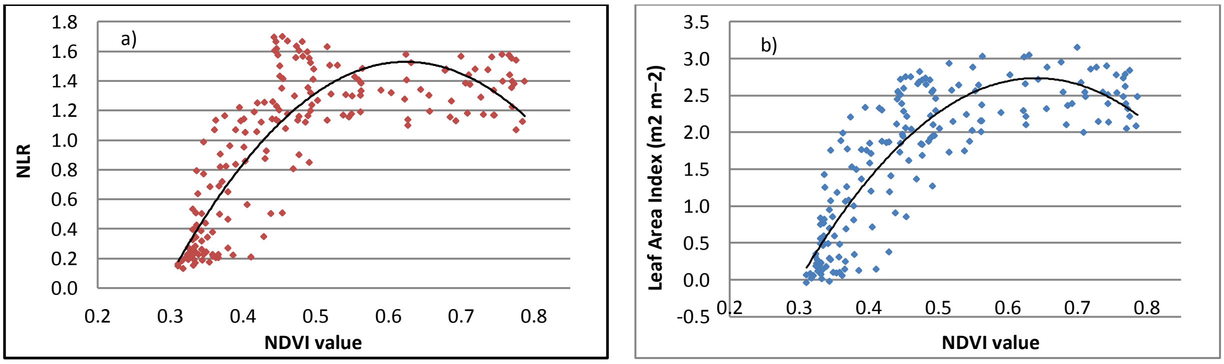

Fig. 6 Scatter plot describing the correlation between a) NDVI and NLR (r=0.77); b) NDVI and LAI (r=0.81)

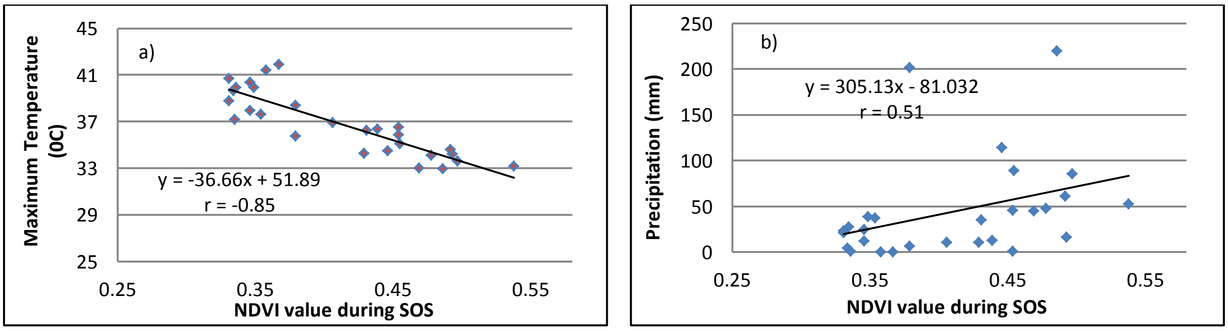

Fig. 7 Scatter plot describing the correlation between a) maximum temperature with NDVI; b) precipitation with NDVI during the start of growing season (April-May)

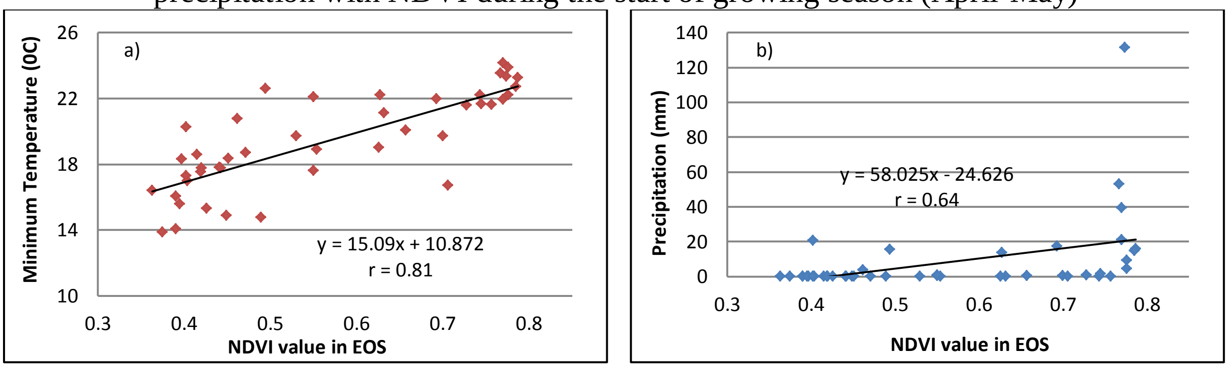

Fig. 8 Scatter plot describing the correlation between a) minimum temperature with NDVI; b) precipitation with NDVI during the end of growing season (October-December)

teak plantation are shown in Fig. 2, 3 and 4 respectively. Rainy season starts in March to May, the same time as the leaf of teak plantation starts to bud reflecting by the gradual increase of NDVI values. Rainy season ends in October and November, corresponding to the decrease of NDVI values in this period of time (Fig. 2).

During April which is the hottest month in a year, NDVI value was lowest, indicating the leafless period of teak plantation. NDVI value increased from 0.35-0.40 to 0.75-0.80 during May to October, and then it decreased in November and December (Fig. 3, 4). Growing season ended in January, February or March in different areas.

The linear correlation between NDVI with LAI and NLR was found, confirming the cloud free data set. It is found that NDVI was significantly correlated with LAI (r = 0.81, p<0.0001), and NLR (r = 0.77, p<0.0001) (Fig. 6). This correlation is consistent to other previous reports. For example, relationship between NDVI and field measured LAI in deciduous forests were reported by Madugundu *et al* [24]. In their study, NDVI was strongly correlated with LAI (r^2=0.68, p≤0.05) but showed evidence of saturation above a biomass of 100 g/m^2 and an LAI of 2 m^2/m^2 [25]. Potithep *et al* [23] has also found that NDVI changes in relation to the seasonal variations of LAI [26]. These results indicate that the preprocessing NDVI derived from satellite is sufficient to capture the teak forest phenology.

B. Phenological Metric of Teak Plantation

Based on the phenological metrics extracted from TIMESAT program, SOSs varied among these three years, which start at 96, 152 and 80 day of year (DOY) in 2009, 2010 and 2011, respectively (Table I). SOS in 2010 was delayed comparing to other years. El Niño in 2010 may lead to this change in phenology (Fig. 3, 4).

TABLE I. PHENOLOGICAL METRICS OF TEAK PLANTATION PERIOD 2009-2012

Year	SOS (DOY)	EOS (DOY)	LOS (Day)
2009-2010	96 (April)	60 (March)	324 days
2010-2011	***152 (May)***	63 (March)	***264 days***
2011-2012	80 (March)	22 (Jan)	295 days

On the other hand, EOSs in 2009, 2010 and 2011 were on 60, 63 and 22 DOY, respectively. As a result of the changes in SOS and EOS, LOS in 2010 with El Niño was about 264 days, shorter than in 2009 and 2011 by about 60 and 31 days, respectively. In general, analysis from phenology metrics shows that LOS of teak plantation ranged between 264 and 324 days. SOS occurred from March to May while EOS occurred in January or March of the following year.

The patterns of teak forest phenology extracted from MODIS NDVI are consistent with those previously reported. Yoshifuji et al [14] concluded that canopy duration of tropical seasonal forest is about 300-320 days.

C. NDVI and Its Response to Climate Variables

The Spearman correlation coefficient between NDVI (8 days period, 250m resolution) and climate factors was calculated. Results indicate that NDVI was significantly and negatively correlated with maximum temperature (r = -0.85, p<0.0001), positively correlated with precipitation (r = 0.51, p<0.0001) in the period of April – May (Fig. 7). During EOS (October to December), NDVI had a significant and positive relationship with minimum temperature and precipitation (r = 0.81 and r = 0.64, p<0.0001, respectively) (Fig. 8). These results imply that growing season might start when temperature decreases with precipitation increases during April to May. Thus, the results suggest that climate variables such as precipitation and temperature were the main controlling factors for NDVI, corresponding to plant phenology.

However, more analysis on this relationship is needed to be conducted at teak plantations with different topography and climate conditions, in order to test the hypothesis that precipitation and temperature control teak phenology and obtain further understanding on phenology and climate variation, especially under the context of climate changes.

IV. CONCLUSIONS

In this study, four years time series of MODIS NDVI image were processed with cloud removal in order to investigate the phenological variations driven by climate variability. From the results, we concluded that;

- Processed MODIS NDVI was able to capture the changes of phenology of a teak plantation in this study.
- The SOS of teak plantation was delayed in El Nino year, with significant effects on the variations of LOS among four years in this study.
- Teak forests NDVI have stronger relationship to maximum and minimum temperature than precipitation.
- Further analysis on phenological metrics (such as comparison with photographs and field sensor data) in relationship to meteorological variables is required for further understanding of relationship between teak plantation phenology and climate variation, especially under the context of climate changes.

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