Journal of the Indian Society of Soil Science, Vol. 62, No. 4, pp 376-383 (2014)

# Soil Nutrient Dynamics of Mature Rubber (*Hevea brasiliensis* Muell. Arg.) Plantation in Relation to Phenology and Growing Environment

**S. Meti[1*], M. Meerabai[2], M. Abdul Salam[3], J. Jacob and Vijayaraghavakumar[2]**
*Rubber Research Institute of India, Kottayam, 686009, Kerala*

Para rubber (*Hevea brasiliensis* Muell. Arg.) is grown on varied soil and climate condition in traditional rubber growing regions of India. Owing to its attractive profit, natural rubber (NR) is being grown beyond its ideal elevation of 300 m but poor performance at high elevation has been reported. Hence, a study was undertaken to understand the soil nutrient dynamics and phenology of mature rubber plantation at different elevation induced growing environment in Kottayam district of Kerala. Climate, particularly maximum ($T_{max}$) and minimum ($T_{min}$) temperature, rate of litter decomposition, nitrogen (N) mineralization potential, dynamics of soil organic carbon (SOC), total N and exchangeable aluminium (Al) showed significant variation along the elevation gradient. Litter decomposition rate, N mineralization potential were low at high elevation resulting in longer SOC turnover period and hence significant increase in SOC content with increase in elevation was noticed. Dynamics of soil total N showed peak for short period at high elevation compared to low elevation. Number of new flushes were less and annual leaf shedding was early at high elevation indicating the shortened growing period compared to low elevation. Rubber tree at high elevation showed significantly higher nutrient resorption for P and K indicating the limited availability of these nutrients. Factor analysis extracted mineralization and climate factors at high elevation and only climate factor showed significant positive correlation with next month rubber yield indicating the importance of climate factor in rubber ecosystem at high elevation. At low elevation extracted climate component did not show significant correlation with rubber yield, indicating climate condition at low elevation is not limiting rubber performance. Present study showed the use of elevation gradient as a potential natural resource for studying climate effect on nutrient dynamics, plant phenology and performance.

**Key words:** Rubber, phenology, mineralization, elevation, nutrient dynamics

Natural rubber (NR) is best suited for cultivation up to 300-350 m elevation. Owing to its attractive profit and stable price compared to other plantation crops, many enterprising farmers have taken up NR cultivation beyond 350 m elevation. A six month delay in attaining tappable girth for every 100 m rise in elevation beyond 200 m has been observed due to 0.6 $^0$C temperature decline for every 100 m increase in elevation (Dijkman 1951; Moraes 1977). Many environmental factors vary with elevation. So elevation gradient brings climate variation which includes varying regimes of temperature, precipitation, nitrogen (N) availability, *etc*. Potential net soil N mineralization (Garten and Miegroet 1994) and turnover time of labile soil carbon (Garten *et al.* 1999) vary along climate gradient associated with changes in elevation. Distinct difference in phenology is noticed between rubber grown in north-east India and traditional NR growing area. Alteration in phenology is likely to have effect on the adaptation and finally performance of a species. Elevation induced changes in soil nutrient dynamic and plant phenology are receiving more attention in many other tropical trees, but such studies are lacking in NR. Studying the soil nutrient dynamics and NR phenology at different elevation gradient was felt more relevant in the context of extension of rubber cultivation to newer areas as well as changing climatic condition.

*Corresponding author (Email: shankarmeti@gmail.com)
*Present address*
[1]University of Horticulture Sciences, Bagalkot, Karnataka
[2]College of Agriculture, KAU, Vellayani, Thiruvananthapuram, Kerala
[3]Calicut University, Kerala

**Table 1.** Geographical location of the holdings selected for the study

| Elevation | Holding | Latitude | Longitude | Elevation (m) |
|---|---|---|---|---|
| High (> 300 m) | I | 9°35′30.24″ | 76°51′14.7″ | 399 |
| | II | 9°35′17.10″ | 76°51′22.8″ | 432 |
| Medium (200-300 m) | I | 9°32′31.50″ | 76°51′08.2″ | 204 |
| | II | 9°35′02.60″ | 76°50′49.1″ | 186 |
| Low (0-100 m) | I | 9°34′14.84″ | 76°46′46.78″ | 70 |
| | II | 9°34′26.50″ | 76°49′17.2″ | 82 |

## Material and Methods

*Site Description and Collection of Samples*

Kottayam district (latitude 9.41° to 9.71° and longitude of 76.36° to 76.59°) representing the major rubber growing district of Kerala having different growing environment and elevation was selected for the study. Using advanced space borne thermal emission and reflection radiometer (ASTER) digital elevation model (DEM), Kottayam district was divided into three growing environments based on three elevation classes *viz*., low (0-100 m), medium (100-300 m) and high (> 300 m). Two rubber holdings/estates of Rubber Research Institute of India (RRII) 105 clone of age 10-15 year old in each of three elevation classes were identified and global positioning system (GPS) readings were recorded to confirm their locations coming within the three elevation classes (Table 1). From each holding, four rubber trees of uniform girth were selected as observational plants and paint marked. Four sampling spots were marked with peg around each observational tree and collected surface soil sample (0-30 cm) at monthly interval. At the beginning of leaf shedding period (November-December), leaf samples were collected for assessing nutrient resorption efficiency (NRE) following the method of Finzi *et al.* (2001).

$$\text{NRE (\%)} = \frac{\text{Nutrient conc. of green leaf - Nutrient conc. of ripened leaf}}{\text{Nutrient concentration of green leaf}} \times 100$$

*Leaf Litter Sampling and Decomposition*

Leaf litter fall was collected during January 2011 from 1 $m^2$ area at 5 locations in each holding and dry weight was recorded and expressed in t $ha^{-1}$. Rate of leaf litter decomposition was assessed following litter bag method (Bocock and Gilbert 1957). In each holding 10 nylon litter bag of size 30 × 30 $cm^2$ with mesh of 2-mm were placed. Litter bag containing 100 g of rubber litter were placed randomly in contact with surface soil during February 2011. Half of litter bags were randomly recovered during June 2011 and rest during September 2011. Recovered litter was oven dried and recorded dry weight. Loss in dry weight was expressed as per cent of initial litter weight.

*Chemical Properties of Soil Samples*

Soil samples collected at monthly interval were analyzed for soil organic carbon (SOC), mineral N content (ammonia + nitrate N), exchangeable Al and pH following standard procedures. Nitrogen mineralization was assessed during August 2011 following the modified *in-situ* soil core method (Raison *et al.* 1987).

*Recording Observations*

Tree girth was recorded from selected observational trees at quarterly interval. At monthly interval, observational trees as well as whole block were visually assessed for occurrence of the phenological events like leaf shedding, leaf flushing, leaf maturity, flowering and fruit growth. In addition, occurrence of leaf disease caused by *Oidium heveae* Steinm (powdery mildew) and *Phytopthora palmivora* Butl. (Abnormal leaf fall) were also noted. Rubber yield was recorded from selected holdings at each elevation at monthly interval and expressed as gram per tree per tap. Weather parameters like rainfall, maximum and minimum temperature were recorded daily at one location in each elevation classes.

*Data Analysis*

The data collected from the experiment were analyzed by two way ANOVA technique with elevation and months as factors (Gomez and Gomez 1984). Factor analysis was done to represent correlated variables with small homogeneous set of factors/components that represent underlying process/factor and are independent of one another. Factors were extracted following principle component analysis method. Factors whose eigen value was more than one were only selected. Based on loading of dominant variables into selected component, each component was named and Pearson correlation coefficient was estimated to assess relation between extracted component and rubber growth and yield.

**Table 2.** Annual litter fall and leaf litter nutrient content at different elevation

| Elevation | Annual litter fall (t ha$^{-1}$) | Leaf fall due to disease | | Leaf litter nutrient content (%) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | *Phytophthora** (g m$^{-2}$) | *Oidium* (kg ha$^{-1}$) | *N | P | K | Ca | Mg |
| Low | 1.67 | 31.5 (5.79)$^{c}$ | 429.7 | 1.53 (1.59) | 1.67 | 2.13 | 1.6$^{b}$ | 0.24$^{b}$ |
| Medium | 1.95 | 81.5 (9.33)$^{b}$ | 384.3 | 1.58 (1.60) | 1.95 | 1.73 | 1.71$^{ab}$ | 0.24$^{b}$ |
| High | 1.92 | 204.4 (14.67)$^{a}$ | 222.5 | 1.57 (1.60) | 1.92 | 1.73 | 1.88$^{a}$ | 0.32$^{a}$ |
| *S.Em* | 0.13 | 0.94 | 58.96 | 0.03 | 0.13 | 0.03 | 0.06 | 0.02 |
| *CD (P=0.05)* | NS | 2.86 | NS | NS | NS | NS | 0.20 | 0.06 |

*Square root transformed; Figures in parentheses are transformed data

**Table 3.** Leaf litter decomposition at different elevation

| Elevation | Litter decomposition (%) | | Mean of elevation |
|---|---|---|---|
| | After 120 days | After 210 days | |
| Low elevation | 42.5 | 66.1$^{a}$ | 54.3$^{a}$ |
| Medium elevation | 37.2 | 68.8$^{a}$ | 59.9$^{a}$ |
| High elevation | 25.2 | 53.5$^{b}$ | 40.6$^{b}$ |
| Mean of period | 40.4$^{b}$ | 62.8$^{a}$ | 51.6 |
| *S.Em* | 9.3 | 5.8 | |
| *CD (P=0.05)* | NS | 12.4 | |
| Pooled analysis | Elevation (A) | Period (B) | A × B |
| *S.Em* | 4.9 | 3.8 | 4.6 |
| *CD (P=0.05)* | 10.5 | 7.8 | NS |

## Results and Discussion

*Litterfall and Decomposition*

Annual leaf litter addition in rubber ecosystem was around 1.67-1.9 t ha$^{-1}$ yr$^{-1}$ and it did not vary significantly along elevation (Table 2). Litterfall constitutes a major portion of nutrient cycling between plant and soil and it acts as an input-output system of nutrients (Das and Ramakrishnan 1985). Rate of litter decomposition varied significantly along elevation (Table 3). The rate of litterfall and its decomposition regulate energy flow, primary productivity and nutrient cycling in ecosystem (Waring and Schlesinger 1985). Rate of litter decomposition after 210 days of incubation was significantly higher at low (66.1%) and medium elevation (68.8%) compared to high elevation (53.5%) (Table 3). At 120 days after incubation, leaf litter decomposition rate did not vary significantly among elevation. Pooled analysis of data indicated that rate of litter decomposition at 210 days of incubation was significantly higher than rate of decomposition at 120 days of incubation. Interaction between elevation and period factors did not vary significantly.

There were no reports on variation in rubber litter decomposition rate among elevation, however rubber litter decomposition studied using litter bag technique by Philip and Abraham (2009) reported 75 per cent by 210 days. Influence of geographical variables such as latitude and longitude on litter decomposition has been reported earlier in other species (Aerts 1997; Silver and Miya 2001) and this variation was attributed to the geographical difference in temperature along latitude (Zhang *et al.* 2008). In the present study, $T_{max}$ at high elevation was low compared to low elevation, and $T_{min}$ during summer at high elevation was low compared to low elevation (Fig.1, 2).

Decomposition rate is reported to decline exponentially as temperature falls along elevation gradient (Vitousek *et al.* 1994) and hence high elevation showed significantly low rate of decomposition. High rate of litter decomposition at low elevation could be

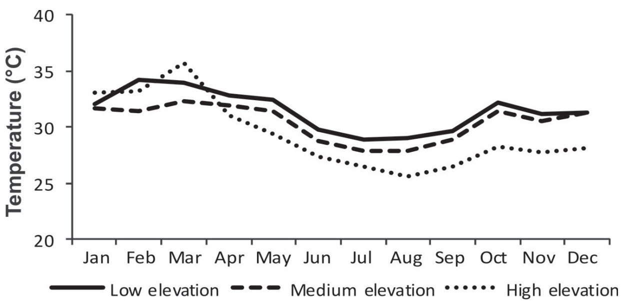


**Fig. 1.** Maximum air temperature at different elevation

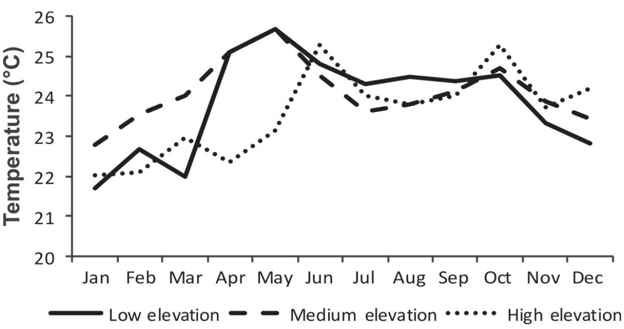


**Fig. 2.** Minimum air temperature at different elevation

**Table 4.** Monthly soil organic carbon (%) at different elevation

| Elevation | Feb 2011 | Mar | Apr | May | Jun | Aug | Sep | Oct | Nov | Dec | Jan 2012 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | 2.29 | 2.9 | 1.8 | 2.1 | 1.9 | 2.1 | 2.6 | 1.7 | 2.5 | 2.4 | 2.5 | 2.19 |
| | (0.36) | (0.46) | (0.25) | (0.31) | (0.28) | (0.32) | (0.41) | (0.23) | (0.39) | (0.38) | (0.38) | (0.34) |
| Medium | 2.75 | 3.1 | 2.0 | 2.4 | 2.2 | 2.3 | 2.7 | 2.0 | 2.6 | 2.5 | 2.4 | 2.40 |
| | (0.44) | (0.49) | (0.29) | (0.37) | (0.35) | (0.35) | (0.43) | (0.29) | (0.41) | (0.39) | (0.38) | (0.38) |
| High | 3.47 | 2.4 | 2.5 | 2.8 | 2.7 | 3.0 | 3.5 | 3.4 | 3.5 | 3.4 | 3.4 | 3.02 |
| | (0.54) | (0.36) | (0.40) | (0.45) | (0.43) | (0.47) | (0.54) | (0.52) | (0.54) | (0.53) | (0.53) | (0.48) |
| Mean | 2.80 | 2.8 | 2.0 | 2.4 | 2.2 | 2.4 | 2.9 | 2.2 | 2.8 | 2.8 | 2.7 | 2.51 |
| | (0.44) | (0.44) | (0.31) | (0.38) | (0.35) | (0.38) | (0.46) | (0.35) | (0.44) | (0.44) | (0.43) | (0.40) |
| | | | Elevation | | | Month | | | Interaction | | | |
| *S.Em* | | | 0.03 | | | 0.02 | | | 0.09 | | | |
| *C.D. (P=0.05)* | | | 0.06 | | | 0.03 | | | 0.17 | | | |

Figures in the parentheses are $Log_{10}$ transformed data

**Table 5.** Monthly soil mineral nitrogen (ammonium + nitrate) at different elevation (mg $kg^{-1}$)

| Elevation | Feb 2011 | Mar | Apr | May | Jun | Aug | Sep | Oct | Nov | Dec | Jan 2012 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | 1.78 | 1.84 | 1.72 | 1.92 | 1.93 | 2.0 | 2.0 | 1.51 | 1.43 | 1.59 | 1.58 | 1.72 |
| | (70.1) | (75.4) | (59.5) | (90.0) | (97.1) | (85.6) | (35.3) | (30.1) | (47.1) | (45.4) | (48.9) | (64.7) |
| Medium | 1.94 | 1.91 | 1.96 | 1.94 | 2.0 | 2.08 | 2.0 | 1.33 | 1.51 | 1.44 | 1.40 | 1.75 |
| | (90.9) | (97.9) | (109) | (112.6) | (124.9) | (102.4) | (22.0) | (34.6) | (28.0) | (25.7) | (50.9) | (66.7) |
| High | 1.67 | 1.73 | 1.60 | 1.86 | 2.10 | 1.86 | 1.45 | 1.31 | 1.54 | 1.22 | 1.70 | 1.63 |
| | (57.4) | (53.9) | (42.7) | (77.6) | (127.6) | (74.6) | (30.6) | (21.7) | (31.9) | (21.2) | (52.6) | (55.7) |
| Mean | 1.78 | 1.84 | 1.75 | 1.93 | 2.04 | 1.95 | 1.43 | 1.42 | 1.52 | 1.36 | 1.69 | 1.70 |
| | (71.5) | (75.7) | (68.0) | (96.5) | (107.8) | (99.5) | (37.3) | (37.3) | (44.3) | (36.6) | (59.1) | (62.2) |
| | | | Elevation | | Month | | | Interaction | | | | |
| *S.Em* | | | 0.03 | | 0.06 | | | 0.10 | | | | |
| *C.D. (P=0.05)* | | | 0.07 | | 0.12 | | | 0.20 | | | | |

Figures in the parentheses are $Log_{10}$ transformed data

attributed to favourable temperature condition stimulating the activity of decomposer community, thereby accelerating the litter decomposition (Zhang *et al.* 2008). Except Ca and Mg, the nutrient content of litter did not vary significantly along elevation range (Table 2). Calcium in the plant influences the cell structural properties, especially of cell wall (Rice 2007) and plays important role in the resistance to diseases (Agrios 2005). Magnesium is the essential component of chlorophyll in the plant. Matured and green leaves are shed by abnormal leaf fall disease, whose intensity was high at higher elevation compared to low elevation (Table 2). Thus green and matured leaves fallen due to abnormal leaf fall disease constituted the major portion of annual leaf litter fall at high elevation. Thus the Ca and Mg content of leaf litter was significantly higher at high elevation compared to low and medium elevation.

*Soil Nutrient Dynamics*

Soil nutrient dynamics particularly, SOC (Table 4), mineral N (Table 5) and exchangeable Al (Table 6) showed significant influence by elevation gradient. The SOC showed significant increase with elevation and numerous studies have indicated increased SOC stock with increase in altitude (Townsend *et al*. 1995; Trumbore *et al.* 1996; Bolstad *et al*. 2001). During active growing period (April-August) decline in SOC at high elevation was less and it was for short period compared to low elevation (Table 4). This indicated less decomposition of soil organic carbon by microbes due to unfavourable temperature at high elevation. Decreased decomposition rate with increasing elevation is a direct cause of humus accumulation at high elevation. So turn over time of soil carbon increases with elevation (Townsend *et al*. 1995; Trumbore *et al*. 1996). Lower decomposition rate is linked to reduced nutrient mineralization particularly N. At high elevation, N mineralization potential was low compared to that at low elevation (Fig. 3). Temporal mineral N showed peak value for a short period at high elevation compared to low elevation (Table 5). So far, there are no reports on effect of elevation on N mineralization potential in rubber plantation, however reports of lower mineral N content in rubber growing soil at higher altitude compared to lower altitude has

**Table 6.** Monthly soil exchangeable aluminium at different elevation [cmol($p^+$)$kg^{-1}$ soil]

| Elevation | Feb 2011 | Mar | Apr | May | Jun | Aug | Sep | Oct | Nov | Dec | Jan 2012 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | 3.08 | 1.53 | 1.33 | 0.45 | 1.22 | 1.27 | 0.49 | 0.61 | 1.02 | 1.29 | 1.10 | 1.22 |
| | (1.75) | (1.22) | (1.03) | (0.68) | (1.01) | (1.11) | (0.67) | (0.69) | (0.97) | (1.09) | (1.00) | (0.99) |
| Medium | 2.98 | 2.44 | 2.08 | 0.94 | 2.32 | 2.10 | 1.60 | 1.26 | 1.99 | 2.47 | 2.18 | 2.08 |
| | (1.73) | (1.52) | (1.44) | (0.95) | (1.51) | (1.43) | (1.28) | (1.10) | (1.41) | (1.56) | (1.48) | (1.40) |
| High | 3.05 | 2.68 | 2.20 | 0.92 | 2.72 | 2.01 | 1.15 | 1.52 | 2.11 | 2.36 | 2.55 | 2.44 |
| | (1.74) | (1.63) | (1.48) | (0.96) | (1.64) | (1.41) | (1.06) | (1.22) | (1.45) | (1.53) | (1.59) | (1.43) |
| Mean | 1.63 | 1.46 | 1.32 | 0.86 | 1.39 | 1.31 | 1.00 | 1.00 | 1.27 | 1.40 | 1.36 | 1.27 |
| | (2.66) | (2.13) | (1.74) | (0.74) | (1.93) | (1.72) | (1.00) | (1.00) | (1.61) | (1.96) | (1.83) | (1.61) |

| | Pooled analysis | | |
|---|---|---|---|
| | Elevation | Month | Interaction |
| *S.Em* | 0.11 | 0.04 | 0.13 |
| *C.D. (P=0.05)* | 0.24 | 0.07 | 0.25 |

Figures in the parentheses are square root transformed data

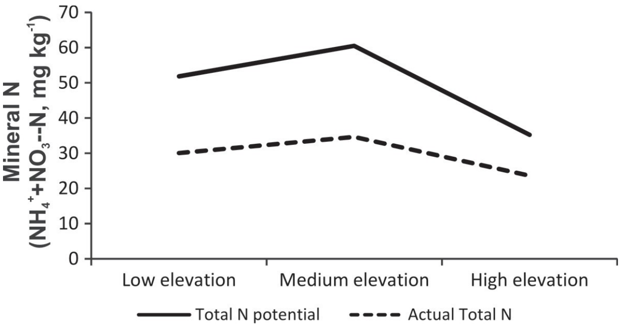


**Fig. 3.** Nitrogen mineralization potential at different elevation

been reported from India (Satisha *et al*. 2000), Nigeria (Eshett and Omueti 1989) and South-East Brazil (Centurion *et al*. 1995). Soils in traditional rubber tract are inherently deficit in available P (Osodeke and Kamalu 1992) and organic P constitutes major share. Because of slow mineralization of organic carbon at high elevation, the turn over time of SOC was high resulting in locking of more organic P. Also high exchangeable Al at high elevation (Table 6) might have led to more P-fixation. Foliar resorption, the process of nutrient re-translocation from old leaves into storage tissue during senescence was significantly higher for P and K at high elevation compared to low elevation (Table 7). High re-translocation of P and K

**Table 7.** Nutrient resorption efficiency of rubber at different elevation

| Elevation | Nutrient resorption efficiency (%) | | |
|---|---|---|---|
| | N | P | K |
| Low elevation | 53.2 | 63.0[b] | 38.0[b] |
| Medium elevation | 44.9 | 58.2[b] | 44.1[b] |
| High elevation | 40.8 | 80.3[a] | 67.8[a] |
| *S.Em* | 4.9 | 7.3 | 10.9 |
| *CD (P=0.05)* | NS | 15.6 | 23.4 |

at high elevation indicated short circulation of these nutrients at high elevation rubber ecosystem. Because of this reason, trees might have resorted to resorption of more P from senescing leaves so as to meet the requirement of emerging leaves. Being mobile nutrient, K is vulnerable to leaching losses. High exchangeable Al at high elevation replaced the much of K held at exchangeable site and replaced K lost through leaching at high elevation. Hence, trees resorbed more K from senescing leaves to overcome shortage.

*Rubber Phenology and Yield*

Seasonal arrangement of life cycle events (phenophase) is important for survival and reproductive success of plant. At high elevation rubber trees showed less number of new flushes and early annual leaf fall compared to low elevation (Fig. 4). At high elevation abnormal leaf fall disease occurred one month early compared to low and medium elevation. Rubber at high elevation produced less number of new flushes due to low temperature as well as low rate of mineralisation and availability of N for short period. After August/September, SOC at high elevation was maintained at steady level compared to low elevation indicating the slowdown of mineralization activity and hence mineral N was relatively low at high elevation during this period. Exchangeable Al during October/November at medium and high elevation was significantly high (Table 6). High exchangeable Al is known to cause reduced root growth (Foy 1988), and as a result, trees face nutrient and/or water stress. Added to this, trees at high elevation experienced severe leaf fall due to abnormal leaf fall disease during August-October (Fig. 4) which was little earlier compared to low elevation followed by annual leaf fall in November due to winter temperature, thus resulting in shortening of active growing period.

| Elevation | | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | | Flowering | | New flush | Flowering | New flush | | New flush | | New flush | | Wintering | New flush |
| | | Oidium | Fruit growth | Oidium | Fruit growth | | | | Phytophthora disease | | | | Oidium |
| Medium | | Flowering | | New flush | Flowering | New flush | | | | New flush | | Wintering | New flush |
| | | Oidium | Fruit growth | Oidium | Fruit growth | | | | Phytophthora disease | | | | Oidium |
| High | | Flowering | | New flush | | | New flush | | | | | New flush | Flowering |
| | | Oidium | Fruit growth | Oidium | Flowering | | Oidium | Phytophthora disease | | | Wintering | | Oidium |

**Fig. 4.** Phenological stages of rubber at different elevation

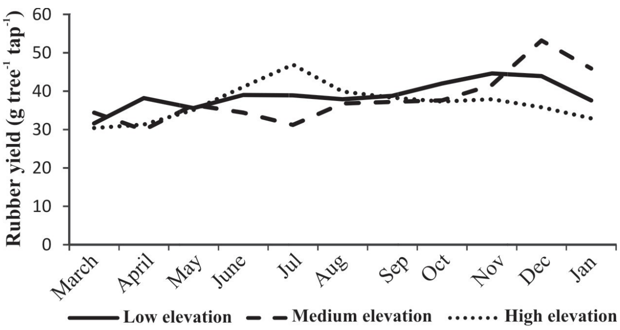


**Fig. 5.** Monthly dry rubber yield at different elevation

Perusal of the data on latex yield revealed peak yield during winter period (November-December) at low and medium elevations (Fig. 5). Such a peak rubber yield during winter period was reported by Priyadarshan (2011). This higher yield may be due to the favourable temperature which stimulated and favoured latex flow and production. It is contradictory to note that at high elevation rubber yield was low during this winter period. Severe leaf fall during September/October due to abnormal leaf fall disease and low temperature during subsequent winter has put rubber at high elevation under more stress.

Defoliation is a phenomenon to circumvent moisture and low temperature stress through minimizing transpiration so as to ensure reproduction (Priyadarshan 2011). So rubber at high elevation showed early wintering/leaf shed and refoliation. Refoliation and subsequent flowering utilized large amount of carbohydrate reserve and hence yield during November/December was low at high elevation compared to low and medium elevation. Active growth period of rubber coincided with monsoon period during which peak nitrogen mineralization was observed. Rubber yield was low during monsoon period at low and medium elevation due to competition from developing leaves and fruit for the carbohydrates. Low latex production was also attributed to short sunshine duration during rainy season (Ailiang 1984). However, at high elevation, rubber yield was comparatively more. Because of the early refoliaton and less number of new flushes during monsoon, there may be less competition from the developing leaves and fruit for the carbohydrates. At the same time, minimum temperature at high elevation was low during monsoon period which might have favoured latex flow resulting in more rubber yield. While studying the rubber cultivation at high altitude in China, Ailiang (1984) also reported that low temperature at high elevation benefited the latex flow, but not benefited the growth of rubber. Soil nutrient dynamics particularly nitrogen, showed perfect match with active growth and mismatch with peak yield phase of rubber at low and medium elevation. Peak yield coincided with low N mineralization period and low yield with peak N mineralization period at low and medium elevation and hence rubber yield showed significant negative relation with N. At high elevation, low and peak yield phase matched with mineralization pattern and hence it showed non-significant positive relation.

*Factor Analysis*

Factor analysis extracted two components at all three elevations. Based on loading of variables, at low elevation components were named as climate factor and soil factor and at medium elevation components were named as mineralization and temperature factors (Table 8). Similarly, at high elevation components were mineralization and climate factor. Climatic factor showed significant positive correlation with next month rubber yield at high elevation indicating the importance of minimum temperature and rainfall in rubber ecosystem at high elevation (Table 9). It is evident that altitudinal related changes in climatic conditions, litter decomposition rate and soil nutrient dynamics has altered the rubber phenology and yielding phase particularly at high elevation. Altitudinal induced changes in climate, soil nutrient dynamics particularly N and phenological changes has effectively reduced the growing period and resource acquisition by rubber trees at high elevation. This might

**Table 8.** Loading of variables into components at different elevation

| Low elevation | | | Medium elevation | | | High elevation | | |
|---|---|---|---|---|---|---|---|---|
| Variables loaded | Comp. 1 (Climate factor) | Comp. 2 (Soil factor) | Variables loaded | Comp. 1 (Mineralization factor) | Comp. 2 (Temperature factor) | Variables loaded | Comp. 1 (Mineralization factor) | Comp. 2 (Climate factor) |
| pH | -0.15 | **0.91** | pH | -0.17 | -0.26 | Exch. Al | 0.27 | **-0.90** |
| OC | -0.64 | -0.26 | $NH_4^+$-N | **0.93** | 0.29 | $NH_4^+$-N | **0.96** | 0.11 |
| Total N ($NH_4^+$ +$NO_3^-$-N) | 0.29 | **0.80** | $NO_3^-$-N | **0.96** | -0.11 | $NO_3^-$-N | **0.93** | 0.01 |
| Soil moisture | **0.90** | 0.06 | Total N ($NH_4^+$ + $NO_3^-$-N) | **0.97** | 0.20 | Total N ($NH_4^+$ + $NO_3^-$-N) | **0.99** | 0.07 |
| $T_{max}$ | **-0.73** | 0.07 | $T_{max}$ | -0.25 | **0.83** | Soil moisture | 0.13 | **0.85** |
| $T_{min}$ | **0.92** | 0.04 | $T_{min}$ | 0.28 | **0.72** | $T_{min}$ | 0.261 | **0.69** |

Extraction Method: Principal Component Analysis

**Table 9.** Correlation of different component with rubber yield at three elevations

| Component | Low elevation | | Medium elevation | | High elevation | |
|---|---|---|---|---|---|---|
| | Comp 1 | Comp. 2 | Comp. 1 | Comp. 2 | Comp. 1 | Comp. 2 |
| Current month yield | 0.22 | -0.29 | **-0.64*** | -0.21 | 0.33 | 0.14 |
| Next month yield | 0.40 | -0.30 | **-0.67*** | -0.17 | 0.45 | **0.81**** |

*Correlation is significant at the *P=0.05* level, **Correlation is significant at the *P=0.01* level.

be the reason for the reported poor performance and increased immaturity period of rubber with increase in altitude (Foth and Turk 1973). At low elevation, extracted climate component did not show significant correlation with rubber yield indicating that climate condition at low elevation is not limiting rubber performance.

In the context of projected change in climate particularly temperature, ecosystem processes are likely to be altered (IPCC 2007). This may result in increased nutrient supply and thus may enhance the productivity of rubber at high elevation. Analysing the impact of climate warming on natural rubber productivity in different agro-climatic regions in India, Satheesh and Jacob (2011) reported that NR productivity in Kerala may be reduced by 4-7 per cent and that in cold prone North-East India could be up by 11 per cent in the next decade if present trend of warming continues. Since SOC and N mineralization showed negative trend with elevation, increasing temperature under climate change situation may further enhance N mineralization at lower elevation. This may result in a faster decline of SOC, affecting the nutrient supplying capacity of soil, thus affecting the productivity of rubber.

## Conclusions

Present study indicated lower nitrogen mineralization potential, slow litter decomposition rate and long turnover time of soil carbon with increase in altitude due to variation in climate associated with elevation gradient. With the results from such experiments based on natural altitudinal gradient, one can easily infer the consequence of climate change on ecosystem processes. Under the scenario of projected increase in temperature due to climate change, rubber growing areas at higher elevation may become more suitable but at the same time at lower elevation soil organic carbon mineralization and litter decomposition may be enhanced resulting in decline of soil health and productivity over long run.

## Acknowledgement

Author express thanks to the Chairman, Rubber Board, Kottayam for granting study leave for pursuing Ph.D. and the Deputy Director (Agronomy/Soils), RRII, Kottayam for providing support and facility to successfully complete the research work.

## References

Aerts, R. (1997) Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystems: a triangular relationship. *Oikos* **79**, 439-49.

Agrios, G.N. (2005) *Plant Pathology*. Amsterdam, Elsevier Academic Press.

Ailiang, J. (1984) A geo-ecological study of rubber tree cultivation at higher altitude in China. *Proceedings of*

*International Rubber Conference,* 17-19 September 1984 Colombo, pp. 117-130.

Bocock, K.L. and Gilbert O.J. (1957) The disappearance of leaf litter under different woodland conditions. *Plant and Soil* **9,** 179-185.

Bolstad, P.V., Vose, J.M. and McNulty, S.G. (2001) Forest productivity, leaf area, and terrain in southern Appalachian deciduous forests. *Forest Science* **47,** 419-427.

Centurion, J.F, Centurion, M.A.P.C. and Andrioli, I. (1995) Rubber growing soils of Sau Paulo, Brazil. *Indian Journal of Natural Rubber* **8**, 75-84.

Das, A.K. and Ramakrishnan, P.S. (1985) Litter dynamics in *Khasi* pine of northeast India. *Forest Ecology and Management* **10**,135-153.

Dijkman, M.J. (1951) *Thirty years of research in the Far East*. University of Miami press, Florida, p 329. *Dresel Institute Technology* **8**, 1-104.

Eshett, E.T. and Omueti, J.A.J. (1989) Potential for rubber cultivation (*Hevea brasiliensis)* on basaltic soils of *South-East* Nigeria: climate, pedochemical and mineralogical consideration. *Indian Journal of Natural Rubber* **2**, 1-8.

Finzi, A.C., Allen, A.S., DeLucia, E.H., Ellsworth, D.S. and Schlesinger, W.H. (2001) Forest litter production, chemistry and decomposition of following two years of free-air $CO_2$ enrichment. *Ecology* **82**, 470-484.

Foth, H.D. and Turk, L.M. (1973) *Fundamentals of Soil Science.* Wiley Eastern Pvt. Ltd., New Delhi.

Foy, C.D. (1988) Plant adaptation to acid, aluminium-toxic soils. *Communications in Soil Science and Plant Analysis* **19,** 959-987.

Garten, Jr. C.T. and VanMiegroet, H. (1994) Relationship between soil N dynamics and natural $^{15}N$ abundance in plant foliage from Great Smoty Mountain National Park. *Canadian Journal of Forest Research* **24,** 1636-1645.

Garten, Jr. C.T., Post, III W.M., Hanson, P.J. and Cooper, L.W. (1999) Forest soil carbon inventories and dynamics along an elevation gradient in the southern Appalachian Mountains. *Biogeochemistry* **45,** 115-145.

Gomez, K.A. and Gomez, A.A. (1984) *Statistical Procedures for Agricultural Research*. 2nd Edition, John Wiley Publication, p. 680.

IPCC (2007) Fourth *Assessment Report (AR4), Climate Change 2007: The physical Science Basis*. Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (S.D. Solomon, M. Qin, Z, Manning, M. Chen, K.B. Marquis, M, Averyt, M. Tignor and H.L. Miller, Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, USA.

Moraes, V.H.F. (1977) Rubber. In *Ecophysiology of Tropical Crops* (P. de T. Alvin and T.T. Kozlowski, Eds.), pp. 315-331. Academic press, New York.

Osodeke, V.E. and Kamalu, O.J. (1992) Phosphorus status of *Hevea* growing soils of Nigeria. *Indian Journal of Natural Rubber Research* **5**, 107-112.

Philip, A. and Abraham, J. (2009) Litter chemistry and decomposition in rubber plantation. *Natural Rubber Research* **22**, 10-16.

Priyadarshan, P.M. (2011) *Biology of Hevea Rubber*. CAB International, Oxfordshire, UK, p. 226.

Raison, R.J., Connel, M.J. and Khanna, P.K. (1987) Methodology for studying fluxes of soil mineral N in situ. *Soil Biology and Biochemistry* **19**, 521-530.

Rice, R.W. (2007) The Physiological Role of Minerals in Plants. In *Mineral Nutrition and Plant Disease* (L.E. Datnoff, Wade H. Elmer and D.M. Huber, Eds.). American Phytopathological Society, 9-30.

Satheesh, P.R. and Jacob, J. (2011) Impact of climate warming on natural rubber productivity in different agroclimatic regions of India. *Natural Rubber Research* **24**, 1-9.

Satisha, G.C., Dey, S.K., Pal, T.K. and Varghese, Y.A. (2000) Soil nutrient status of slope lands under *Hevea brasiliensis* in Mizoram at varying altitude and their relationship with soil properties. *Indian Journal of Natural Rubber Research* **13**, 46-55.

Silver, W.L. and Miya, R.K. (2001) Global patterns in root decomposition: comparisons of climate and litter quality effects. *Oecologia* **129,** 407–419.

Townsend, A.R., Vitousek, P.M. and Trumbore, S.E. (1995) Soil organic matter dynamics along gradients in temperature and land use on the island of Hawaii. *Ecology* **76,** 721-733.

Trumbore, S.E., Chadwick, O.A. and Amundson, R. (1996) Rapid exchange between soil carbon and atmospheric carbon dioxide driven by temperature change. *Science* **272,** 393-396.

Vitousek, P.M., Turner, D.R., Parton, W.J. and Sanford, R.L. (1994) Litter decomposition on the Mauna Loa environmental matrix, Hawaii Patterns, mechanisms and models. *Ecology* **75,** 418-429.

Waring, R.H. and Schlesinger, W.H. (1985) *Forest Ecosystem: Concepts and Management*. Academic Press, New York, p. 211.

Zhang, D., Hui, D., Luo, Y. and Zhou, G. (2008) Rates of litter decomposition in terrestrial ecosystems: global patterns and controlling factors. *Journal of Plant Ecology* **1**, 85-93.

Received 08 July 2014; Received in revised form 16 August 2014; Accepted 2 December 2014