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Article

Tropical Montane Cloud Forest Characteristics in Southern Thailand

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Abstract

The climatic, vegetation and soil characteristics of several tropical montane cloud forests in southern Thailand were investigated. Automatic weather stations were installed at three study sites: Mt. Nom cloud forest, Dadfa cloud forest and Mt. Nan Headquarters. HOBO U23 Pro V2 Temperature/Relative Humidity data loggers along the Mt. Nom elevational transect at five sites (500, 700, 900, 1,100 and 1,300 m) were installed for measuring air temperature and relative humidity. Soil samples along the Mt. Nom elevational transect at the same five sites were collected and soil pH, soil moisture and organic content were measured in the laboratory. Tree height, shrub width, leaf thickness, leaf area and epiphyte cover of every *Lithocarpus bennettii* (Miq.) Rehd. tree found along the Mt. Nom cloud forest elevational transect starting at 313 m and ending at 1,274 m were measured. Of the three sites, Mt. Nom cloud forest had the lowest air temperature, dew point, heat index, solar radiation, solar energy and UV index. Soil moisture and soil organic content increased with increasing elevation. The soil pH ranged from 3.6 to 4.3 which indicated that soil at Mt. Nom is high acidic.

Keywords: Climatic factor, epiphyte cover, rainfall, relative humidity, soil, temperature, Thailand

Introduction

Tropical montane cloud forests occur in a mountainous altitudinal band frequently enveloped by orographic clouds [1,2]. This forest obtains moisture deposited from fog in addition to bulk precipitation [2,3]. The main climatic characteristics of cloud forests include frequent cloud presence, usually high relative humidity and low irradiance [2]. This kind of forest typically occurs at elevations between 1,500 to 3,300 m occupying an altitudinal belt of approximately 800 to 1,000 m at each site. The lowermost occurrence of low-statured cloud forest (300 - 600 m a.s.l.) is reported from specific locations like small islands, where the cloud base may be very low and the coastal slopes are exposed to both high rainfall and persistent wind-driven clouds [1].

Tropical montane cloud forests (TMCF) are complex, relatively rare and one of the world's most threatened ecosystems due to climatic warming, human impacts and the high deforestation rate which is greater than all other tropical forests [4-6]. These TMCFs typically have high levels of endemism, low rates of net primary production and play an essential role in the hydrologic cycles of tropical mountains [1-2,7-8] Deforestation of a TMCF takes centuries to recover due to its slow growth rate.

Tropical montane cloud forests are important affecting the hydrological balances at regional scales and the biodiversity that they support. Tree species richness may be low on tropical mountains but epiphytic abundance and diversity are higher than in other types of forest [9]. In montane tropical forests, fog represents an increasingly important water source as rainfall and temperature decrease with increasing elevation and relative humidity [10].

High fog frequency and generally high air humidity on tropical mountains favour accumulation of epiphytic biomass, particularly of non-vascular species [11]. The average non-vascular epiphyte cover of tropical montane forest trees was estimated to be between 40 - 50 % [12,13]. In addition to high fog and humidity, low wind speeds and the presence of long-lived trees favour epiphyte biomass [14].

Tree stature and leaf sizes decrease but epiphyte load increases with elevation [15]. Cloud forest trees are twisted, gnarled, stilt-rooted and stunted trees, thick leaves and often assume an umbrella-like crown [2,16-17]. Cloud forest trees' leaves are thicker, harder and smaller than leaves at lower elevations.

Many studies have reported a variety of soils in TMCFs in the Americas [18,19]. However, soil chemical properties in TMCFs are difficult to generalise [1]. Little has been done on climatic factors, vegetation, soil and their effects on TMCFs in Thailand or Southeast Asia in general. The lack of understanding of cloud forest characteristics makes it difficult to predict what the impacts of climate change will be on cloud forests and their endemic species. This study is the first to investigate the climatic, vegetation and soil characteristics of TMCFs at Mt. Nom cloud forest, Mt. Nan National Park, Nakhon Si Thammarat, Thailand.

There were several hypotheses tested in this study. First, when we compare between TMCFs and tropical rain forests, we predict that (1) TMCFs should have a lower temperature, dew point, heat index, solar radiation, solar energy and UV index than tropical rain forests and (2) TMCF sites should show two distinctive slopes: fog-free days and fog-bound days but tropical rain forests should show only one slope (fog-free days). Secondly, we predict that as elevation increases, (a) temperature should decrease and relative humidity should increase, (b) leaf thickness, and epiphyte cover should increase but leaf area, tree height and shrub width should decrease, and (c) soil organic content and soil moisture should increase but soil pH should decrease.

Materials and methods

Study Site

Mt. Nan National Park with an area of 406 km^2 is located at latitude 8.76908 °N longitude 99.80352 °E, and situated at Noppitam sub-district, Thasala district, and Sichon district in Nakhon Si Thammarat province, Thailand. Geographical characteristics of Mt. Nan National Park are a high mountainous range aligned north-south. Mt. Nan National Park is a tropical mountain forest that is an important watershed source of Nakhon Si Thammarat province. More than 90 % of Mt. Nan National Park is still a primary tropical evergreen forest and is home to a variety of endangered species.

Climatic Characteristics

Davis weather station (Model Vantage Pro II Plus) was installed to collect climatic data every 30 min at 3 locations: Mt. Nom cloud forest (NCF), Dadfa cloud forest (DCF) and Mt. Nan Headquarters (NHQ). Due to different weather station installation periods among these 3 sites, climatic data were used in the data analysis only during 16th January to 19th February 2009. NCF was located at a latitude 8.48698 °N, longitude 99.45000 °E, and elevation 1,274 m a.s.l. (**Figure 1**). NHQ was located at a latitude 8.76908 °N, longitude 99.80352 °E, and elevation 182 m (**Figure 1**). DCF was located at a latitude 9.125360 °N, longitude 99.825531 °E, and elevation 680 m (**Figure 1**). Davis weather stations collect 9 climatic variables: air temperature, relative humidity, dew point, wind speed, heat index, daily rainfall, solar radiation, solar energy, and UV index. The HOBO U23 Pro V2 Temperature/Relative Humidity data loggers were placed along the elevational transect on the north-south slope of Mt. Nom at 5 sites (500, 700, 900, 1,100 and 1,300 m). The HOBO data loggers collected temperature and humidity every 5 min.

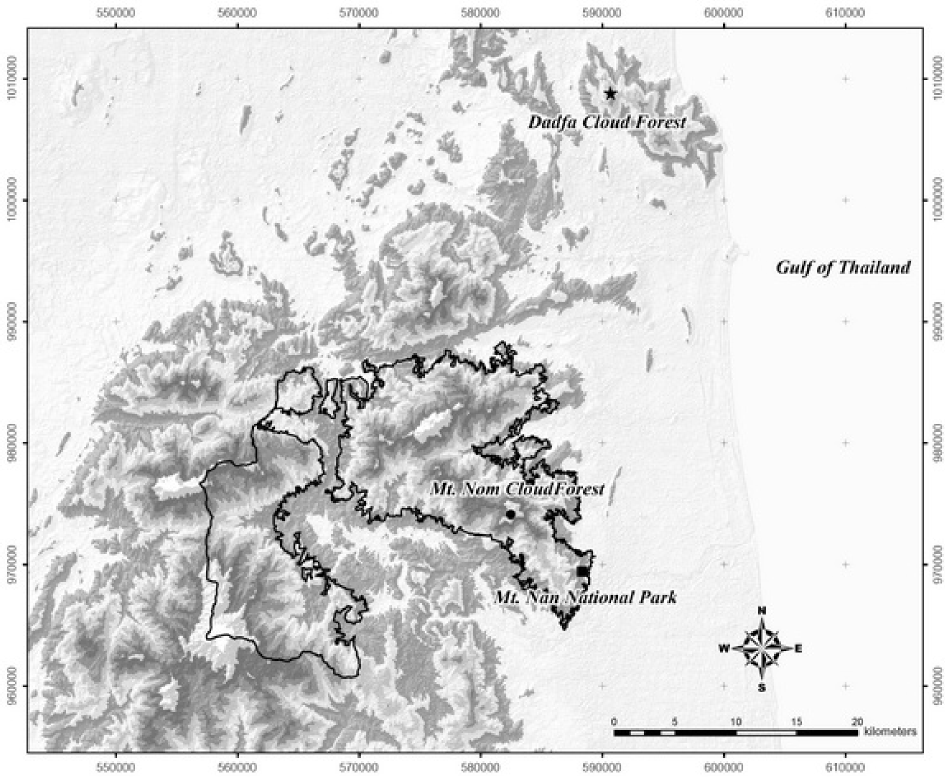


Figure 1 Study sites. ⊙ represents Mt. Nom cloud forest, Dadfa Cloud forest and Mt. Nan Headquarters where the automatic weather stations were installed. Black line represents Mt. Nan National Park boundary.

Vegetation Characteristics

For vegetation characteristics, we measured leaf thickness, leaf area, tree height, shrub width and percent epiphyte cover tree trunks of every *Lithocarpus bennettii* (Miq.) Rehd. tree found on the Mt. Nom elevational transect starting at 313 m and ending at 1274 m a.s.l. *Lithocarpus bennettii* (Miq.) Rehd. trees that had a diameter at breast height between 30 - 35 cm were used in order to control for age differences and the amount of epiphyte cover on tree trunk. This tree species was selected because it was one of few species present from low to high elevations along the Mt. Nom elevational transect.

Five dry leaves were collected and the thickness measured by using a micrometer at 0.001 mm resolution in the field. Photographs of these leaves were taken with a Canon A530, 5 megapixels in the field with white A4 paper. These photographs were analysed for leaf area using Adobe Photoshop and MultiSpec Win 32. A clinometer and a 50 m tape were used to measure tree height and width in the 4 compass directions (i.e. north, east, west, and south). For percentage epiphyte cover, we took photographs of the epiphytes on the *Lithocarpus bennettii* trunk with a Canon A530, 5 megapixels with a camera stand using a rectangular frame with scales on it.

Soil Characteristics

Soil samples at 30 cm depth were collected using a soil auger along the Mt. Nom elevational transect at five sites: 500, 700, 900, 1,100 and 1,300 m. At each elevation, three soil samples were collected and the latitude, longitude and elevation of soil collection sites were measured using a Garmin GPSMAP 76 CSx. Soil samples that contained a lot of pebbles were sieved with a

2 mm size mesh prior to weighing soil samples. 200 g of soil sample was dried in an oven at 90 °C for 24 h, reweighed and percent soil moisture was calculated. Percent soil organic content was determined after burning 50 g of oven dried soil at 550 °C for 1 h, and reweighed [20]. For determining soil pH, 40 g of fresh soil was suspended in 40 ml of deionised water. After 24 h, the pH (H_2O) was measured.

Data Analysis

Parametric statistics tests were used when underlying assumptions were met. One-way ANOVA and Bonferroni post-hoc tests were used to test climate factor differences among NCF, DCF and NHQ. Linear regressions were used to test (1) the association between temperature and relative humidity at NCF, DCF and NHQ, (2) the association between leaf thickness, leaf area, tree height, shrub width, percent epiphyte cover and elevation and (3) the association between percent organic content, percent soil moisture and soil pH with elevation. All significant tests were two-tailed.

Results

Climatic Characteristics

NCF had the lowest temperature, dew point, heat index, solar radiation, solar energy and UV index but had the highest wind speed (**Table 1**). DCF had the highest relative humidity, and NCF had an intermediate relative humidity (**Table 1**). NHQ had higher evapotranspiration than DCF (**Table 1**). There was no difference in the amount of daily rainfall among these three study sites (**Table 1**).

As elevation increased, temperature decreased but relative humidity increased (temperature: y = –0.004x + 22.849, R^2 = 0.192, $F_{1,200258}$ = 4804.22, p < 0.001; relative humidity: y = 0.003x + 88.612, R^2 = 0.011, $F_{1,200258}$ = 215.875, p < 0.001, **Figures 2a,b**).

As air temperature at NCF, DCF and NHQ increased, relative humidity decreased (**Table 2**, **Figures 3a-c**). The relationship between temperature and relative humidity at NCF and DCF differed from NHQ (**Figures 3a-c**).

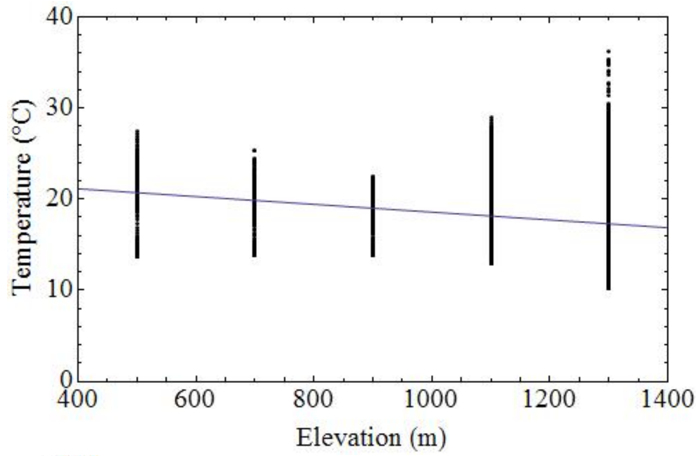
Table 1 Mean (± SD) of climatic factors at Mt. Nom Cloud Forest (NCF), Dadfa Cloud Forest (DCF) and Mt. Nan Headquarters (NHQ). Values in each row with different letters indicate significance at $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Climatic Factor	NCF	DCF	NHQ	Statistics
Air Temperature (°C)	18.9 ± 2.8^a	21.5 ± 2.2^b	25.4 ± 2.6^c	$F_{2,4573}$ = 2515.024***
Relative Humidity (%)	87.9 ± 12.2^a	92.1 ± 10.8^b	84.7 ± 10.2^c	$F_{2,4573}$ = 167.825***
Dew Point (°C)	16.7 ± 2.2^a	20.0 ± 1.5^b	22.5 ± 1.0^c	$F_{2,4573}$ = 4900.758***
Wind Speed (m/s)	1.1 ± 0.9^a	0.4 ± 0.4^b	0.3 ± 0.4^c	$F_{2,4573}$ = 603.656***
Heat Index	19.5 ± 3.1^a	22.8 ± 2.4^b	27.7 ± 3.6^c	$F_{2,4573}$ = 2839.951***
Daily Rainfall (mm)	1.82 ± 4.50^a	2.27 ± 9.86^a	1.32 ± 3.80^a	$F_{2,4573}$ = 0.621
Solar Radiation (W/m^2)	142 ± 221^a	149 ± 242^a	170 ± 240^b	$F_{2,4573}$ = 5.815**
Solar Energy (Ly)	6.12 ± 9.50^a	6.41 ± 10.40^a	7.31 ± 10.30^b	$F_{2,4573}$ = 5.815**
UV Index	1.7 ± 2.8^a	3.0 ± 4.4^b	2.0 ± 3.2^c	$F_{2,4573}$ = 59.536***
Evapotranspiration (mm)	0.05 ± 0.11^a	0.05 ± 0.11^b	0.06 ± 0.12^b	$F_{2,4573}$ = 3.970*

Table 2 Relationship between relative humidity (RH) and air temperature (T) at Mt. Nom Cloud Forest (NCF), Dadfa Cloud Forest (DCF) and Mt. Nan Headquarters (NHQ). *p < 0.05, **p < 0.01, ***p < 0.001.

Location	Regression equation		Statistics
NCF fog-free day	$RH_{ncf} = 4.11\ (42.16 - T_{ncf})$	; $(T_{ncf} > 17.82)$	$R^2 = 0.90$, $F_{1,596} = 5{,}952.690$, $p < 0.001$
	$RH_{ncf} = 100$	; $(T_{ncf} \leq 17.82)$	
NCF fog-bound day	$RH_{ncf} = 27.25\ (20.52 - T_{ncf})$	; $(T_{ncf} > 16.85)$	$R^2 = 0.12$, $F_{1,916} = 127.531$, $p < 0.001$
	$RH_{ncf} = 100$	; $(T_{ncf} \leq 16.85)$	
DCF fog-free day	$RH_{dcf} = 4.95\ (41.32 - T_{dcf})$	; $(T_{dcf} > 21.13)$	$R^2 = 0.86$, $F_{1,512} = 3{,}214.460$, $p < 0.001$
	$RH_{dcf} = 100$	; $(T_{dcf} \leq 21.13)$	
DCF fog-bound day	$RH_{dcf} = 30.09\ (23.43 - T_{dcf})$	; $(T_{dcf} > 20.11)$	$R^2 = 0.07$, $F_{1,322} = 24.684$, $p < 0.001$
	$RH_{dcf} = 100$	; $(T_{dcf} \leq 20.11)$	
Nan Head Quarter	$RH_{nhq} = 4.29\ (45.12 - T_{ncf})$	; $(T_{nhq} > 21.81)$	$R^2 = 0.86$, $F_{1,544} = 9{,}899.240$, $p < 0.001$
	$RH_{nhq} = 100$	; $(T_{nhq} \leq 21.81)$	

(a)



(b)

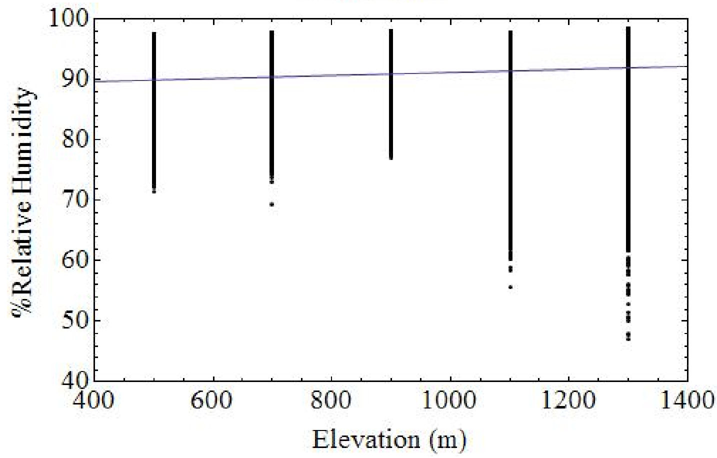


Figure 2 Temperature and relative humidity of NCF from 16th January - 19th February 2009 along the elevational transect (a) Temperature (°C) and (b) Relative humidity.

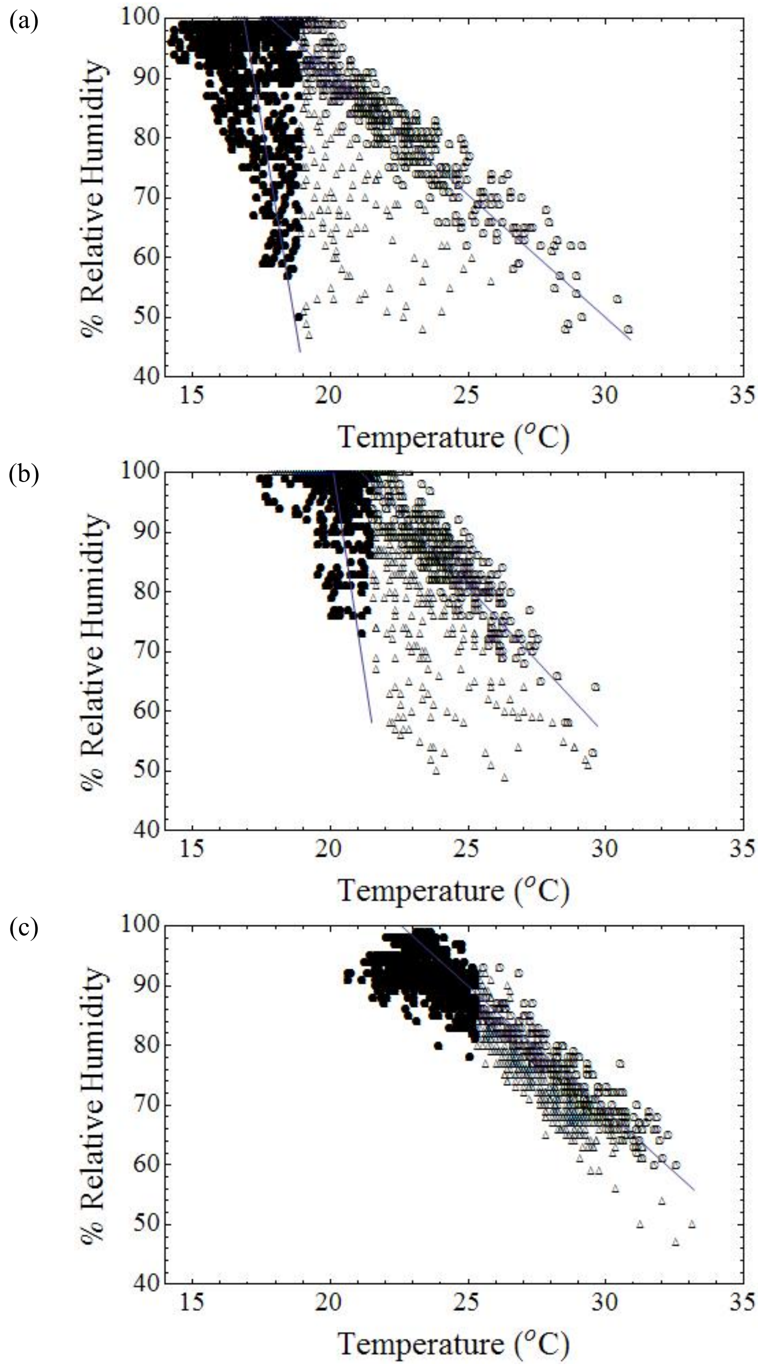


Figure 3 Temperature (°C) and relative humidity at (a) Mt. Nom cloud forest (NCF), (b) Dadfa Cloud forest (DCF) and (c) Mt. Nan Headquarters (NHQ). Open circle, closed circle and triangle represent a fog-free day, fog-bound day and intermediate, respectively.

Vegetation Characteristics

As elevation increased, *Lithocarpus bennettii* leaf thickness increased but leaf area decreased (leaf thickness: $y = 1.067 \times 10^{-5}x + 0.016$, $R^2 = 0.274$, $F_{1,148} = 55.944$, $p < 0.001$; leaf area: $y = -0.032x + 72.698$, $R^2 = 0.232$, $F_{1,143} = 43.276$, $p < 0.001$, **Figures 4a,b**). There was no association between tree height and elevation ($F_{1,23} = 0.0029$, ns, **Figure 4c**). As elevation increased, shrub width decreased but epiphyte cover increased ($y = -0.006x - 14.248$, $R^2 = 0.54$, $F_{1,23} = 27.000$, $p < 0.001$; epiphyte cover: $y = 0.091x - 46.175$, $R^2 = 0.57$, $F_{1,28} = 37.335$, $p < 0.001$, **Figures 4d,e**).

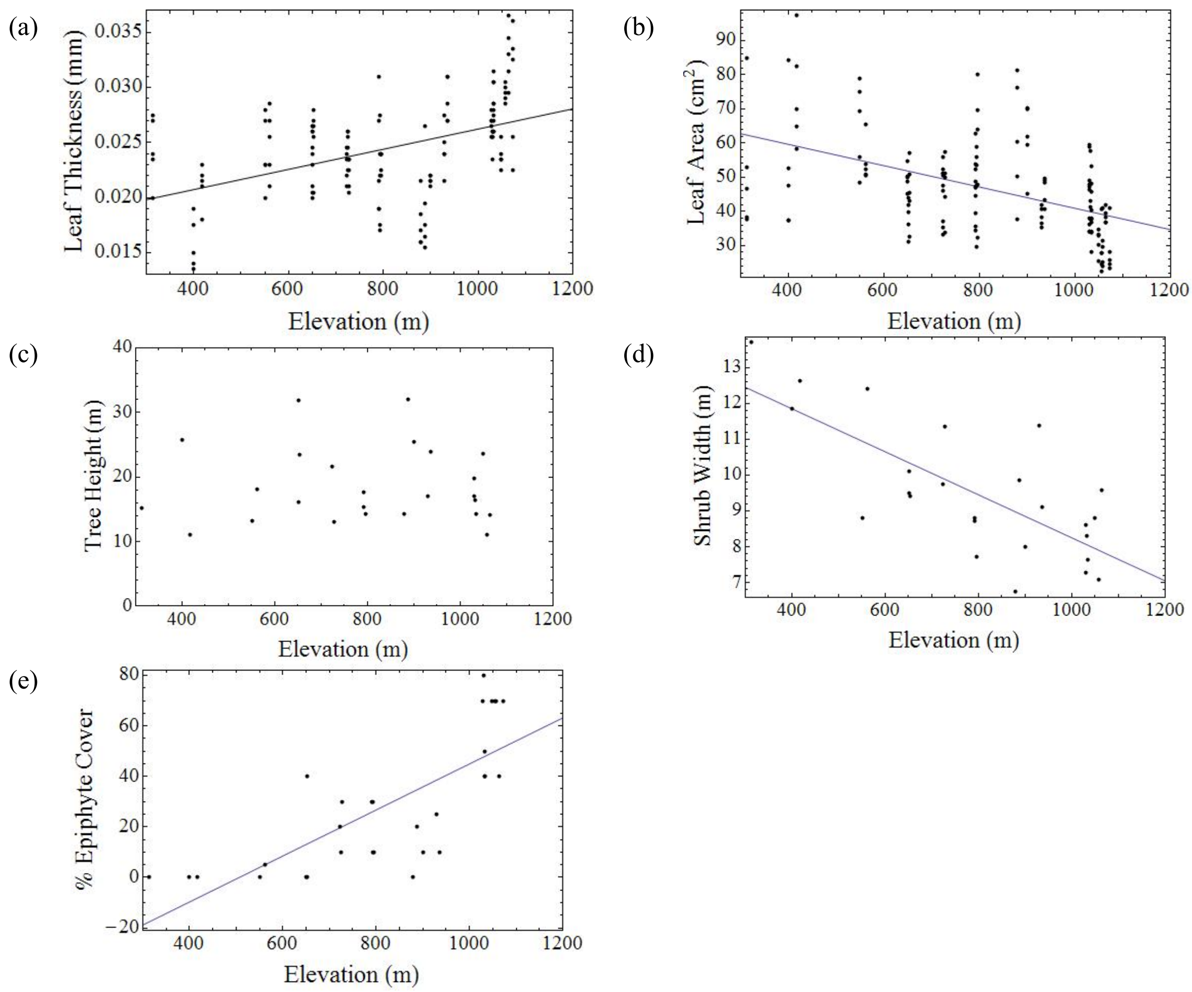


Figure 4 Vegetation characteristics of *Lithocarpus bennettii* at Mt. Nom cloud forest along the elevational transect (a) Leaf thickness (mm), (b) Leaf area (cm^2), (c) Tree height (m), (d) Shrub width (m) and (e) Epiphyte cover (%).

Soil Characteristics

As the elevation increased, percent organic content and percent soil moisture increased (linear regression: percent organic content: y = 0.020x − 2.076, R^2 = 0.485883, $F_{1,13}$ = 12.286, $p < 0.005$; percent soil moisture: y = 0.048x − 6.037, R^2 = 0.456, $F_{1,13}$= 10.911, $p < 0.01$, **Figures 5a,b**). There was no association between soil pH and elevation ($F_{1,13}$ = 1.748, ns, **Figure 5c**).

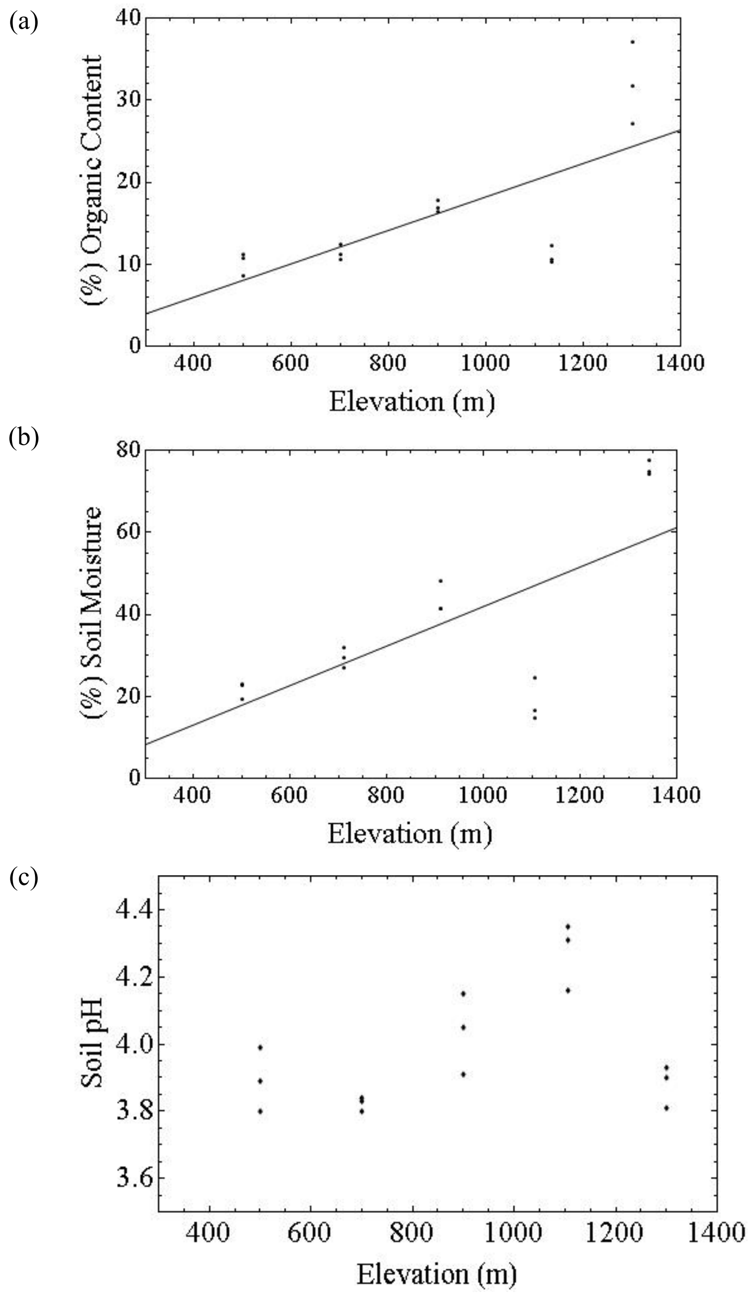


Figure 5 Soil characteristics of Mt. Nom cloud forest along the elevational transect (a) Soil organic content (%), (b) Soil moisture (%) and (c) Soil pH.

Discussion

Richards [12] showed that relative humidity in tropical forest rises with increasing elevation. Our results support Richards's [12] study that temperature decreased but relative humidity increased with increasing elevation. Moreover, temperature and relative humidity at 1,300 m had the highest variation of all elevations. This indicates that Mt. Nom cloud forest has a more severe environment than tropical rain forests. The high relative humidity in TMCFs encourages invasion of leaves by fungi and epiphytes [21].

Grubb and Whitmore [17] categorised TMCFs based on temperature and relative humidity data into three day types: fog-bound, fog-free and intermediate days. They defined a fog-bound day as having no bright sunshine for at least half the daylight hours and a fog-free day as having no fog in the daylight hours and at least 4 h bright sunshine. Our results support Grubb and Whitmore's [17] study that TMCFs at NCF and DCF also can be categorized into three day types: fog-free, fog-bound and intermediate days. On the other hand, NHQ cannot be categorized into three day types. This suggests that having fog-bound and intermediate days were one of the main climatic characteristics of TMCFs.

Previous studies have found that TMCFs are generally complex with abundant mosses, lichens and epiphytes [21-23]. Our results support these studies [5,21-22] suggesting that percent epiphyte abundance and leaf thickness increased with elevation, while leaf area and shrub width decreased. Grubb [21] suggested that leaf thickness and long leaf life meant that less production should be invested in woody parts in TMCFs than in temperate deciduous forest or conifer forest. The thick outer walls may also serve to minimise invasion by fungi [21]. Moreover, low air temperature and lack of bright sunlight at TMCFs also slow down the plant growth. Our results support these findings. Shrub width decreased with increasing elevation. The decline in leaf area with elevation could be an adaptation maximising the ratio of carbon dioxide absorbed to water lost [21].

The stunting of montane forests has received much study, reviewed in [2,7,21]. Kitayama [22] reported that the tree height decreases with increasing elevation in Mt. Kinabalu, Sabah, in Malaysia. However, our results did not support Kitayama's [22] findings. We did not find any association between tree height and elevation. Many studies report that a change from medium-stature forest to small forests corresponds with increasing acidity [24]. Our results on soil pH did not show any association with elevation. Proctor *et al* [24] suggested that the stunted trees might result from higher wind speeds at the summit interacting with drought and rapid drainage from the steep slopes. *Lithocarpus bennettii* (Miq.) Rehd. trees only found up to 1,073 m and not at the summit which was at 1,300 m. Therefore, our results showed no association between tree height and elevation.

Cloud water deposition often increases with elevation, and it is widely accepted that this cloud water increases acid loading in TMCF ecosystems. Cloud water deposition can be 4 times more acidic than bulk precipitation [25]. Since cloud cover tends to increase with elevation, a positive relationship between forest acidification and elevation was expected [25,26]. Our results did not support these previous studies [25,26] in that we did not find soil pH increased with increasing elevation. However, our results showed that, where cloud forest is present, the soil had a lower pH at 1,300 m than at 1,100 m.

Many studies have reported high acidity (pH 2 - 4) at TMCFs [18]. However, other studies have reported pH values over 5 at TMCFs [1,27]. The analysis of the latter group shows that in all the cases the soils occurred on parent material initially rich in bases: limestone, basic volcanic tephras, or it was enriched with volcanic ash. Therefore, it can be assumed that extreme acidity is typical for TMCF soils formed on parent rocks poor in bases [19].

Forest floor moisture content at the upper elevation was significantly higher, which most likely resulted from greater wet deposition from cloud cover [27]. Since cloud water concentrations average about three and a half times higher than bulk precipitation [28], soil organic content commonly increases with increasing precipitation and with decreasing temperature for any particular level of precipitation [29]. The significant positive correlation coefficient between altitude and the amounts of soil organic content in our study suggested that a proportion of the variation in the amounts of soil organic content might be explained by the climate and high dissolved organic content in cloud water.

One reason for the lack of studies in TMCFs in Thailand is their inaccessibility and unfavourable environment for humans. Fortunately, their inaccessibility and harsh climate, with high rainfall and relative humidity, has also limited their exploitation. Since TMCFs are usually enveloped in clouds and fog, carrying out field work is not an easy task. Nevertheless, an increasing amount of research is being conducted in these ecosystems.

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