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Effects of Altitude and Shade-Tree Types on Large Cardamom Chlorophyll, Nitrogen and Spectral Properties in the Sikkim Himalaya

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ABSTRACT

The response of plant canopy to radiation as Normalised-Difference Vegetation Index (NDVI), and chlorophyll and nitrogen content in large cardamom (*Amomum subulatum* Roxb.) were studied under agroforestry systems at three elevations in the Sikkim Himalaya. Large cardamom is a high-value, low-volume, non-perishable and perennial cash crop grown as understorey in agroforestry systems. N_2-fixing alder (*Alnus nepalensis* D. Don) or mixed species plantations serve as shade trees. Reduction in photosyn-thetically active radiation under the shade compared to open was substantial, 39% reaching the cardamom under *Alnus* and 50% under mixed tree species. Chlorophyll *a*, total chlorophyll and nitrogen of large cardamom were always higher under *Alnus* trees than under mixed tree species. Total chlorophyll and chlorophyll *a* contents of large cardamom leaf and NDVI varied significantly between plantation types and altitudes. Nitrogen content of leaf showed positive relation with total chlorophyll and chlorophyll *a* indicating enhanced productivity of large cardamom under *Alnus* due to nitrogen fixation.

Key Words: *Alnus nepalensis, Amomum subulatum,* Chlorophyll, Vegetation index.

INTRODUCTION

Large cardamom (*Amomum subulatum* Roxb.) is an important perennial crop cultivated mainly between 600 m to 2500 m elevations of the Sikkim Himalayan region. It is a native of the eastern Himalaya and distributed widely in the hills of Darjeeling, eastern Nepal, Sikkim and Bhutan. Its cultivation is one of the most distinctive livelihood option for the mountain people with an approximate turnover of US$ 8 million (Sharma et al. 1994), occupying more than 23500 ha of land in the Sikkim state (Figure 1). The capsule (fruit) is used as spice/condiment and contains about 3% essential oil rich in cineole (Gupta et al. 1984). This crop is usually cultivated on steep slopes under tree cover either in natural forest or plantations. New plantations of large cardamom-based agroforestry systems have mono-cultures of alder (*Alnus napalensis* D. Don) as shade trees.

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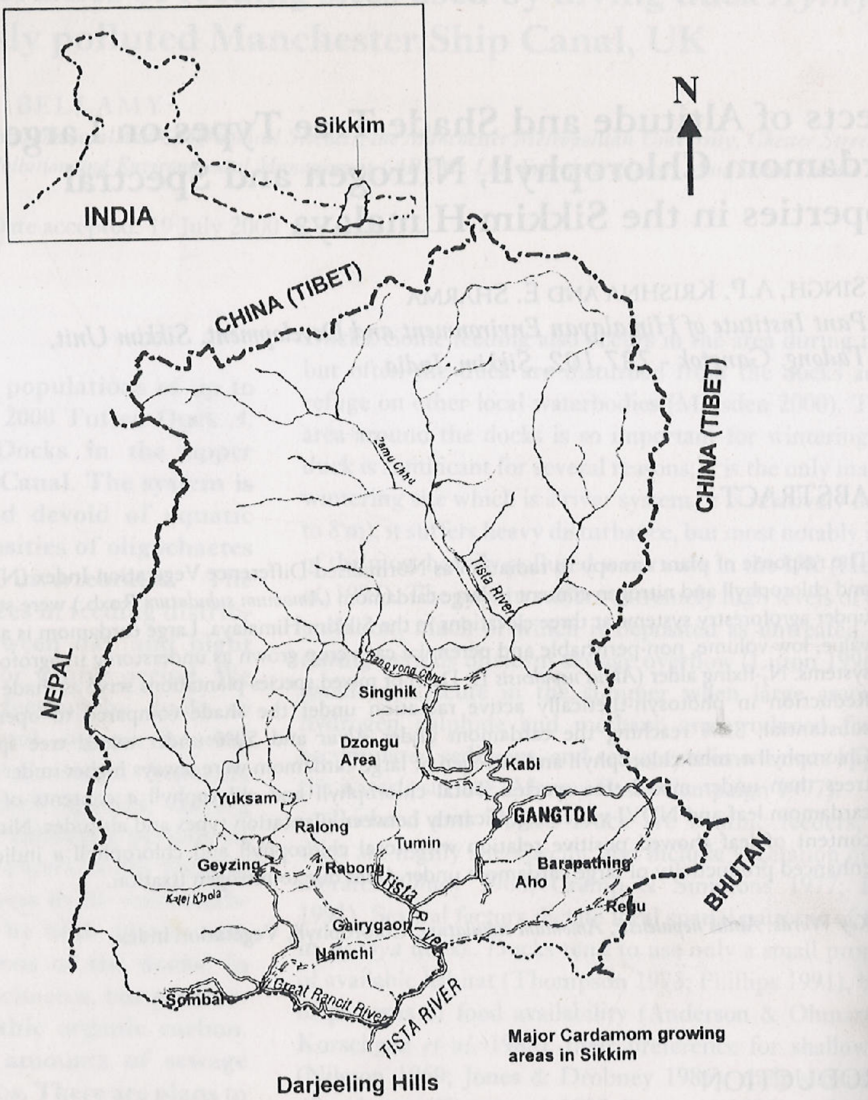

Figure 1. Location of large cardamom growing areas in Sikkim and study sites

Plant productivity is dependent upon many factors, including intrinsic CO_2 uptake rate, environmental factors (climate, nutritional and water status of the soil), genetic variability and light intercepting leaf area. All these processes and variables change during the growing season showing typical pattern in life span. Results from a number of studies suggest that N_2-fixing woody plants have the capacity to accelerate N cycling and increase plant productivity. Actinorhizal (*Frankia* nodulated) symbiotic N_2-fixing species can contribute significant amounts of fixed nitrogen to temperate forest ecosystems (Dawson 1983, Sharma and Ambasht 1984, 1988, Batzli and Dawson 1997) leading to increased growth of co-occurring species (Cote and Camire 1984, Batzli and Dawson 1997) as expected in large cardamom agroforestry with *Alnus nepalensis*.

The response of plant canopies to radiation is a function of the intensity of radiation in various spectral regions, and the absorbing and transmitting properties of the vegetation (Gates et al. 1965). Chlorophyll content is one of the important parameters of structural aspects of the ecosystem and may be considered as an index of primary productivity in the ecosystem (Curran 1983, Curran et al. 1990). Leaves reflect little in the blue and red (R) wavelengths due to absorption by photosynthetic pigments, and reflect strongly in the near-infrared (NIR) due to intra- and inter-leaf scattering (Knipling 1970, Tucker 1979, Curran 1983). Making use of these properties of plants, the remote sensing studies utilise the vegetation index such as Normalised-Difference Vegetation Index [(NDVI = (NIR-R) / (NIR+R)] for enhancing the contrast between soil and vegetation reflectances (Law and Waring 1994). Response of plant canopy to radiation as NDVI was estimated under different canopies and elevations.

The main objective of the present work is aimed to study and evaluate the effects of N_2-fixing *Alnus* and non-N_2-fixing mixed tree species at different altitudes on nitrogen, spectral properties and chlorophyll content of large cardamom leaves.

LOCATION AND CLIMATE

The cardamom-based agroforestry systems under investigation are located at three altitudes viz., Aho Basti (800 m) in East district, Kabi (1500 m) in North district and Garry (2000 m) in South district of Sikkim in Eastern Himalaya (Figure 1). Maximum and minimum temperatures at all the sites varied between 25°C and 2°C respectively, during investigation. Mean relative humidity ranged from 78 to 85% at these sites.

MATERIALS AND METHODS

Cardamom plantations of about 15-years old grown under *Alnus* (N_2-fixing) and mixed tree species were selected at three altitudes. *Alnus* and mixed trees were also planted by villagers along with the large cardamom as shade is required. Dominating mixed tree species were *Eurya acuminata, Leucosceptrum canum, Symplocos theifolia, Viburnum cordifolium* and *Ficus* spp. Normal density of shade trees maintained ranged between 340-380 trees ha^{-1}. Spectral properties, chlorophyll content and moisture contents of cardamom leaves were estimated at different sites. Sixth to eighth leaflets from the apex (Pathre et al. 1990) were sampled from 15-years old cardamom bush. The leaves were sampled from pseudo-stem at three points of cardamom bush.

For spectral properties, spectroradiometer (Optomech Engineers, Hyderabad, India) with wavelength range of 400-1100 nm was used. Scans of above wavelength range were used for measuring reflectance of both surfaces of the leaf. Field measurements were made at all the sites between 1030 and 1200 hours on clear days in 1997. All measurements were taken during mid-day to avoid shadow effects. The wavelength resolution of the radiometer used covered distinct light peaks of blue, green, red and near infra-red.

Air temperature, relative humidity, and rainfall were recorded using automatic weather station (Campbell Scientific Inc. USA). Photosynthetically active radiation (PAR) was measured using a quantum sensor (LI-190SA, LiCor Inc, Nebraska) on open and under canopy conditions. Chlorophyll content of leaves was determined by the method of Arnon (1949). Nitrogen of cardamom leaf samples were estimated using modified Kjeldhal method (Anderson and Ingram 1993).

RESULTS

Mean annual photosynthetically active radiation (PAR) estimated in the cardamom growing areas ranged from 696 to 1493 μmol m^{-2} s^{-1}. It was lower during winter and rainy seasons, but peaked during the months of April and May. PAR values obtained at different altitudes covered by the study ranged from 376 to 735 μmol m^{-2} s^{-1} during the experiment period (Table 1). The reduction in PAR under the shade compared to open was substantial measuring 39% reaching the cardamom under *Alnus* and 50% under mixed tree species. Large cardamom is a shade loving plant, requires high humidity and is usually cultivated in areas of high rainfall. The moisture content of the cardamom leaf was greatest at 2000 m altitude and smallest at lower elevation (800 m). It varied significantly between sites i.e. altitude and also between plantation types (Table 2).

Table 1. Climatic data and photosynthetically active radiation (PAR) at three elevational sites in Sikkim.

Site/altitude	Air temperature (°C)	Relative humidity (%)	PAR μmol m^{-2} s^{-1}	Annual rainfall (mm)
Aho (800 m)	5.5-25	78	735	2800-3000
Kabi (1500 m)	2.5-24	84	640	3000-3200
Garry (2000 m)	2.0-22	85	376	2300-2500

Total chlorophyll contents were relatively higher in leaves of cardamom grown under *Alnus* than under mixed tree species (Table 2). Total chlorophyll content of cardamom leaf ranged from 4.29 mg g^{-1} dry weight under mixed trees at 1500 m to 10.64 mg g^{-1} dry weight under *Alnus* at 2000 m elevation. Variations between plantation types and altitudes were statistically significant. Chlorophyll *a* in cardamom leaves was always higher than chlorophyll *b*. Chlorophyll *a* varied significantly with both the altitude and plantation types, while chlorophyll *b* content was significant only between plantation types. Nitrogen content of cardamom leaf was always higher under *Alnus* cover compared to mixed tree species. Under mixed tree species nitrogen increased from lower elevation to be highest at the upper most elevation while under *Alnus* cover it increased up to 1500 m elevation only (Table 2). Nitrogen content varied significantly between altitudes and plantation types.

Table 2. Variation in moisture, nitrogen and chlorophyll contents of cardamom leaves grown under *Alnus* and mixed tree species at different altitudes ($n = 3$).

Site/Altitude	Plantation type	Moisture content (%)	Nitrogen (%)	Chlorophyll content (mg g^{-1} dry weight) a	b	Total
Aho (800 m)	Cardamom under *Alnus*	67	2.26	4.15	2.48	6.64
	Cardamom under mixed tree	64	2.02	3.25	1.64	4.89
Kabi (1500 m)	Cardamom under *Alnus*	68	2.88	4.66	2.56	7.22
	Cardamom under mixed tree	66	2.22	2.94	1.35	4.29
Garry (2000 m)	Cardamom under *Alnus*	75	2.52	7.52	3.12	10.64
	Cardamom under mixed tree	71	2.34	4.69	1.69	6.38

ANOVA: Moisture - site $F_{2,18} = 41.3$, $P<0.005$; plantation type $F_{1,18} = 20.4$, $P<0.005$, site × plantation type interaction was not significant. Nitrogen - site $F_{2,12} = 6.25$, $P<0.014$; plantation type $F_{1,12} = 13.67$, $P<0.003$; site × plantation type interaction not significant. Chlorophyll a - site $F_{2,12} = 47.55$, $P<0.0001$; plantation type $F_{1,12} = 70.75$, $P<0.0001$, site × plantation type $F_{2,12} = 5.6$, $P<0.02$, $LSD_{(0.05)} = 0.593$. Chlorophyll b - plantation type $F_{1,12} = 18.91$, $P<0.001$, variation with site, and site × plantation type interaction were not significant. Total chlorophyll - site $F_{2,12} = 10.38$, $P<0.002$; plantation type $F_{1,12} = 44.09$, $P<0.0001$, site × plantation type $F_{2,12} = 6.06$, $P<0.015$, $LSD_{(0.05)} = 1.265$.

Table 3. Normalised-Difference Vegetation Index (NDVI) at different sites along the altitudinal gradients under varying plantation type of large cardamom ($n = 5$).

Site/Altitude	Plants type	NDVI Minimum	NDVI Maximum
Aho (800 m)	Cardamom under *Alnus*	0.400	0.442
	Cardamom under mixed tree	0.378	0.410
Kabi (1500 m)	Cardamom under *Alnus*	0.466	0.584
	Cardamom under mixed tree	0.400	0.472
Garry (2000 m)	Cardamom under *Alnus*	0.490	0.628
	Cardamom under mixed tree	0.448	0.514
ANOVA (*P*-values)[φ]			
Site		0.005	0.005
Plantation type		0.005	0.005
Site × Plantation type		0.005	0.005
LSD (0.05)		0.012	0.016

[φ]Beneath each column, *P*-values associated with an analysis of variance (*ANOVA*) are given, with LSD values ($P = 0.05$) when the interaction is significant. The difference between a specific pair of means for either minimum or maximum NDVI values are significant if it is equal to or more than LSD value.

Both dorsal and ventral surfaces of the cardamom leaf showed similarly strong absorption of radiation between 400-700 nm wavelengths. The minimum and maximum NDVI values of different altitudes and plantation types are presented in Table 3. Analysis of variance showed that both minimum and maximum NDVI values significantly varied between sites located at different elevations and also between plantation types (Table 3). Both maximum and minimum NDVI values increased with elevation and they were always higher under *Alnus* plantation than mixed tree species. Significant correlation of NDVI were found with total chlorophyll [NDVI = 0.322 + 0.073 total chlorophyll; $R = 0.584$, $F_{1,21} = 10.8$, $P<0.005$] and Chlorophyll a [NDVI = 0.251 + 0.158 chlorophyll a; $R = 0.771$, $F_{1,21} = 30.8$, $P<0.005$]. Chlorophyll b did not show any significant correlation with NDVI values. Nitrogen of cardamom leaf also correlated with total chlorophyll [Total chlorophyll = 0.087 + 0.800 nitrogen, $R = 0.517$, $F_{1,16} = 5.824$, $P<0.028$] and chlorophyll a [Chlorophyll a = 0.355 + 0.436 nitrogen, $R = 0.468$, $F_{1,16} = 4.467$, $P<0.05$].

DISCUSSION

Large cardamom is a shade loving plant and requires high moisture content. The moisture content of the large cardamom leaf was greater at higher elevations. The ecological amplitude of the large cardamom is narrow altitudinally but fairly wide in relation to environmental conditions with increasing altitude. Outside this altitudinal range (800-2500 m) cardamom does not perform well. The altitudinal range of *Alnus nepalensis*, which is used as major shade tree, is sympatric with the agroclimatic range of large cardamom farming (Sharma et al. 1998). PAR in the large cardamom growing areas of Sikkim peaked in the months of April and May because of clear summer days. In winter and rainy seasons, the sky was mostly overcast and very few sunny days were observed reducing the PAR reaching the ground.

Chlorophyll a contents of large cardamom leaf varied significantly between plantation types and altitudes. Both minimum and maximum NDVI values like chlorophyll a varied significantly between altitudes and plantation types. A significant positive correlation between chlorophyll a and NDVI values, and their significant sample to sample variation with altitudes and plantation types suggest that these parameters are most appropriate for using in radiometric studies which also forms the basis of application of remote sensing techniques in vegetation function in a broader extent studies. Chlorophyll a can act as productivity indicator while the NDVI as index of light reflectance for vegetation density maps (Hall et al. 1995). Although total chlorophyll and NDVI values also showed significant positive correlation, the sample to sample total chlorophyll variation between altitude was not significant, thus total chlorophyll may not be an ideal parameter for wider use. Chlorophyll a and total chlorophyll of large cardamom were always higher under *Alnus* trees compared to mixed tree species. The roots of *Alnus nepalensis* are nodulated with *Frankia* as an endophyte and are efficient in N_2-fixation (Sharma and Ambasht 1984, Sharma 1988), thus benefiting the understorey large cardamom crop by accelerating the N cycling (Sharma et al. 1994). Most commonly the relationship between nitrogen status and photosynthesis has been investigated by manipulating the nitrogen availability. Photosynthesis-nitrogen relationships are intrinsically complex, because photosynthesis represents the integrated operation of a series of processes sensitive to environmental factors as well as leaf physiology and structure (Field and Mooney 1986). Nitrogen is commonly stored by plants in the form of RuBP carboxylase (Millard 1988), thus the proportion of leaf nitrogen in RuBP carboxylase commonly increases with increasing leaf nitrogen concentration (Evans 1989). As leaf nitrogen concentration increases the photosynthetic rate also increases for which the photon flux densities are required to make efficient use of high leaf nitrogen concentration (Gulmon and Chu 1981, Field 1983, Hirose and Werger 1987). In the present study, total chlorophyll and chlorophyll a showed positive correlation with nitrogen content of the leaf consistent with the above report as chlorophyll is the site of photosynthesis. Large cardamom grows in a diversity of moist habitats in which photosynthetic photon flux density and temperature are the most important environmental factors.

Variation in reflectance is used to assess the composition and types of natural vegetation and crops. This is because of the fact that pigment (chlorophyll and carotenoids) and water content vary according to species, according to growth stage (young and verdant, or dying and yellow), and when plants are diseased or under stress from draught. More importantly, young leaves have higher nitrogen content per unit area than older ones. Generally, they occupy the upper layers in a canopy and receive high photon flux densities. Therefore, this is favourable because leaves with high nitrogen content can utilise high photon flux densities more effectively than those with low nitrogen content (Mooney and Gulmon 1979, Field 1983, Dejong and Doyle 1985). It is hypothesised that the nitrogen content that maximises nitrogen use efficiency is higher under high photon flux density than under low photon flux density.

Most of the tropical forest understorey species may depend strongly on utilisation of sunlight to maintain net carbon gain and growth in its deeply shaded natural habitat. The twin spectral zones of chlorophyll absorption yield an overall vegetation spectral response that in the short wavelength is very similar to that of soils low in the blue region, with a gradual increase in reflectance through the green region. However, in the red absorption region, vegetation reflectance declines considerably, whereas soil reflectance continues to increase. NDVI is one of the important indicators of green vegetation that describes differential reflectance properties in the visible and near-infra-red spectral zones. Greater NDVI values indicate healthy vegetation and high photosynthetic capacity of leaves.

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