ESTIMATION OF FOLIAR NITROGEN OF SAL AND BANJ OAK FORESTS IN WESTERN HIMALAYA USING HYPERSPECTRAL REMOTE SENSING

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ABSTRACT

Nitrogen (N) is an important element for plant growth and development and excellent indicator of forest health status. Hyperspectral remote sensing, a non-destructive technique helps in understanding the forest health by estimating N from the forest ecosystem. In the present study, N has been estimated in pure patches of Oak (*Quercus spp.*) and Sal (*Shorea robusta*) species in the parts of Uttarakhand, India. Vegetation indices using different spectral band combinations were used to identify the appropriate wavelength representing N absorption features. The spectral bands at wavelengths 660 nm, 1517.82nm and 1689.30nm were found to be most suitable for these species. Among all the nitrogen indices, log normalized (1/R) nitrogen index performed better and exhibited strong positive correlations with foliar N content. For Banj oak, N was estimated to be 0.29 to 2.79 ± 0.03 t/ha at R^2 = 0.82 using linear regression equation. Similarly, for Sal species, R^2 achieved maximum at 0.92 and N was estimated to be 0.020 to 0.095 ±0.01 t/ha. The study indicates the utility of hyperspectral data to assess N concentration of Sal and Banj forest for quick monitoring of the forest health. The technique can also be used in indicating the disturbance and degradation in the forest ecosystem.

1. INTRODUCTION

Trees, like every life form, require various nutrients for their growth and development. Nitrogen (N) is an important nutrient for plant growth. N, a part of chlorophyll present in leaf, is required for photosynthesis process (Field and Mooney, 1986), which determines the productivity of the plant. Spectroscopic empirical studies on N and protein concentration in leaves were based on the premise that organic molecular bonds comprising proteins absorb radiation at various peak locations in the wavelength at 1100– 2500 nm near infrared (NIR). Absorption in this region is due to proteins caused by harmonics and overtones of fundamental stretching frequencies of C-H, N-H, and O-H bonds at wavelengths in middle- and thermal-infrared regions (Murray & Williams, 1987). Imaging spectroscopy, one of the advance technologies, has the potential for landscape and regional studies of canopy biochemistry and physiology. Most of this work has focused on temperate forest ecosystems (Kalacska and Sanchez-Azofeifa, 2008), showing that canopy water, leaf pigments, and N can be estimated using hyperspectral imaging. Conventional method of measuring foliar nitrogen in the laboratory involves destructive sampling and is laborious, time consuming and impractical for large and remote landscapes. Remote sensing especially hyperspectral data has immense potential to detect leaf N status from leaf to landscape level. Leaf spectral reflectance provides useful and accurate information of N status in leaf (Yoder and Pettigrew-Crosby, 1995; Kokaly, 2001), while canopy spectral reflectance provides information of N status for the plant as a whole (Hansen and Schjoerring, 2003; Zhu et al., 2008; Yao et al., 2010). Prediction of foliar N and chlorophyll from leaf optical spectra has generally made use of spectral absorption features associated with protein- and pigment-bound N (Kokaly, 2001; Sims and Gamon, 2002; Blackburn, 2006; Ferwerda and Skidmore, 2007). There are several relevant N absorption features of which two vibrational absorptions at 1510nm and 1790nm, caused by proteins, are of specific interest. Protein absorption features are also found in the infrared portion of the spectrum at middle and thermal infrared wavelength regions (Smith et al., 2003). But certain other molecules are also absorbed at the same wavelengths which increase the complexity multifold times.

The wide use of vegetation indices may help to resolve this issue to a greater extent. Till date, very few attempts have been made in the tree species to establish functional relationships between leaf reflectance and leaf N. Reflectance ratios are found to be the best to estimate leaf N and pigments. The reflectance measurements from two or more wavebands are used to analyze specific characteristics of vegetation such as total leaf area and N content. In case of N, empirical relationships were developed based on both direct and indirect correlations with absorption features associated with N-bearing compounds in leaves, e.g., proteins and chlorophyll (Curran, 1989; Kumar et al., 2001). This approach has been extended to ecosystem properties that are functionally linked to canopy chemistry including growth and N cycling. The Normalized Difference Nitrogen Index (NDNI) estimates the relative amounts of N contained in vegetation canopies (Serrano et al., 2002).

The present study has been carried out to estimate the foliar nitrogen content in the selected gregarious forests of Oak (*Quercus spp*.) and Sal (*Shorea robusta*) in the northwest Himalayan foothills using hyperion aboard the NASA's Earth observation-1 satellite. The field studies combined with space borne imaging spectrometry or hyperion sensors will provide possible and reliable empirical estimation of canopy mass N concentration at species level over larger and extended landscapes.

2. STUDY AREA

The study area was selected in Dehradun district of Uttarakhand state of India (Figure 1). It comprises moist deciduous and temperate broadleaved forest. Area selected for N mapping consists of pure and gregarious forest of Sal (*Shorea robusta*) and Oak (*Quercus spp.).* Sal forest was situated at lower altitude, surrounding Doon valley while oak forest was situated at higher altitude than Sal forest. Oak forest was present in the surrounding areas of the Mussoorie city. Annual rainfall in the area ranges from 1000mm to 1500mm.

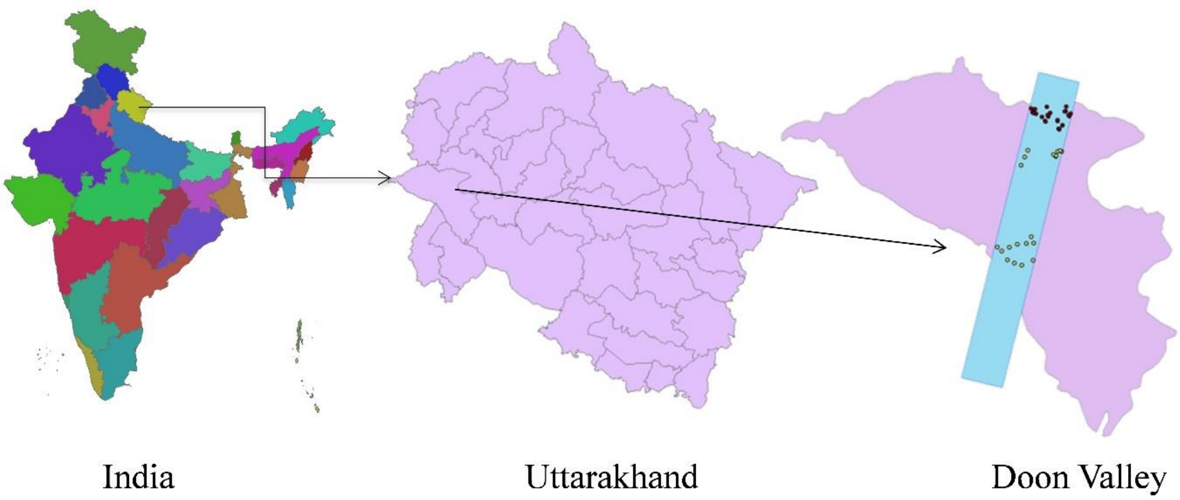


Figure 1: Location of the study area in India and sampling points in the area

3. MATERIAL AND METHOD

The study has been carried out to identify appropriate spectral bands and indices for estimation of foliar N present in the selected species viz., *Quercus spp*. and *Shorea robusta* using regression techniques and to evaluate the applicability of the hyperspectral satellite data in estimation of foliar N in the two gregarious formations. Hyperion sensor aboard EO-1 (Earth Observing 1) satellite was used as hyperspectral data. It contains a total of 242 contiguous bands from 357nm to 2500 nm with approximately 10nm bandwidth. The data is distributed by USGS (United State Geological Survey) and freely available for use. The spatial resolution is 30 m with 7.5 km swath width. Hyperion data used for the study was L1R product and is available in Hierarchical Data Format (HDF) with interleave of BIL (Band Interleaved by Line). Survey of India topographic sheets of 1:50000 scale of number 53-J/6, 7, 10, 11 were used for the background information and field surveys. SVC HR 1024 field spectro-radiometer was used for the collection of leaf spectra and Trimble Juno SB GPS was used for the location information. CHNS (Carbon, Hydrogen, Nitrogen and Sulfur) elemental analyzer was used for the laboratory estimation of total leaf N.

The methodology adopted for the present study is outlined in Figure 2. Processing of the Hyperion image was one of the important tasks as final product is dependent on the information from the image. There are total 242 bands available in Hyperion image but some of the bands are not of good quality as there is little or no information in those spectral regions. Because of this, bad bands are removed and were not considered for further processing. With bad band removal, destripping was also done to fill the gap in some of the regions where information was missing. The missing information are visible in the form of strip hence its correction was called destripping. It was done by averaging the values from neighboring pixel. After this the image was proceeded for the atmospheric correction. It is an important step in the image processing where radiance image was converted into reflectance so that true information about the feature on the ground can be analyzed. Atmospheric correction was done using FLAASH (Fast Line –of-sight Atmospheric Analysis Hypercubes) tool in the ENVI (Environment for Visualizing Images) software. This image was used for the calculation of vegetation indices. NDNI (Normalized Difference Nitrogen Index) (Serrano et al., 2002) was used as a base map for the nitrogen distribution mapping. The index was used as log normalized (eq. 1), without log (eq. 2) and simple ratio (eq. 3), to get the best index for the study. The wavelengths in the index were 1510nm and 1680nm. The information from the image and field was correlated for the prediction model.

$$\mathrm{NDNI} = \frac{\log\left(1/\rho_{1510}\right) - \log\left(1/\rho_{1680}\right)}{\log\left(1/\rho_{1510}\right) + \log\left(1/\rho_{1680}\right)} \quad \text{\_\_\_\_eq. 1}$$

$$\mathrm{NDNI(without\ log)} = \frac{\rho 1510 - \rho 1680}{\rho 1510 + \rho 1680} \quad \text{\_\_\_\_\_eq. 2}$$

$$\mathrm{NDNI(simple\ ratio)} = {\rho 1510}/{\rho 1680} \quad \text{\_\_\_\_\_eq. 3}$$

Field data was collected using stratified random sampling method. In this sampling strategy, the forest type in the area was used as stratum and then random samples were collected from this region. The two forest type Sal, and Oak were considered for sampling. The plot size in this study was used as per the size of the pixel i.e. $30m^2$. The field was carried out to collect the leaf samples of the tree and their respective spectra. Total 5 trees were selected as a representative for the plot. Leaf samples were collected from the top canopy of the tree so that the values can be compared with that of the satellite imagery. Number of trees were also counted in each plot and number of leaves were counted on each representative tree. The leaf count was done on the basis of the number of primary, secondary and tertiary branches and total number of leaves on the tertiary branch. The purpose of the leaf count is to estimate the leaf mass in the plot so that it can represent the true value of the N mass in the area. This N mass was then correlated with the values of the same location in the image of nitrogen index. The best model was selected for the prediction of the foliar N mass map.

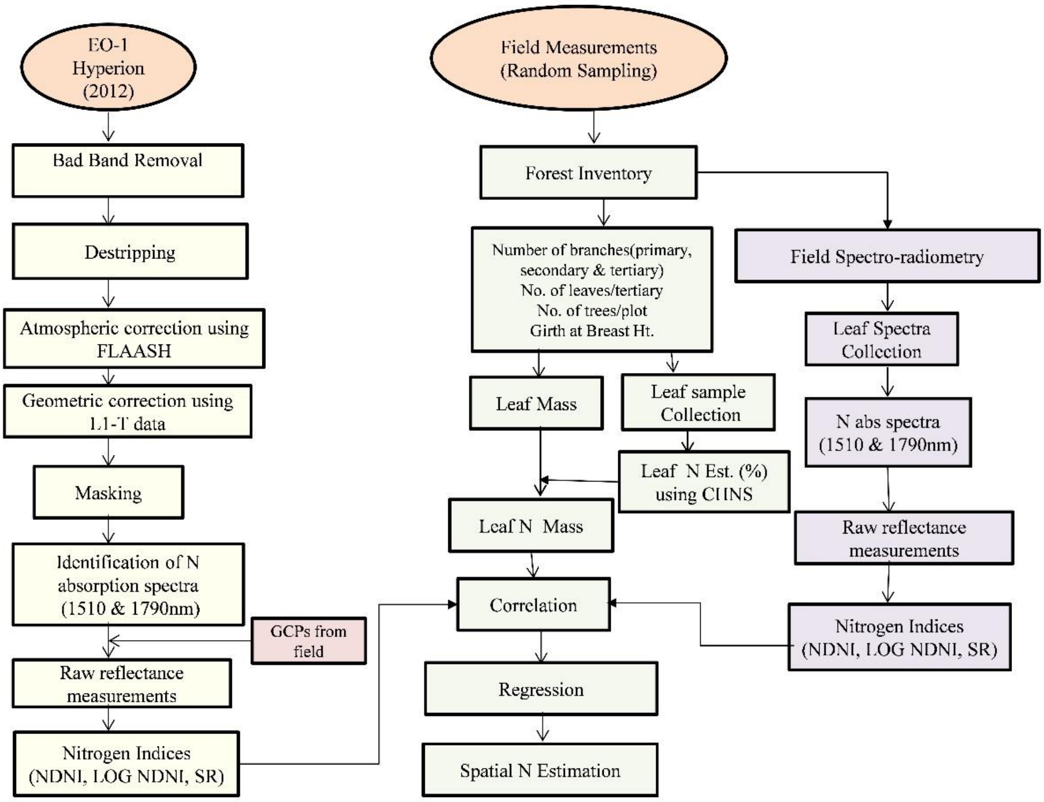
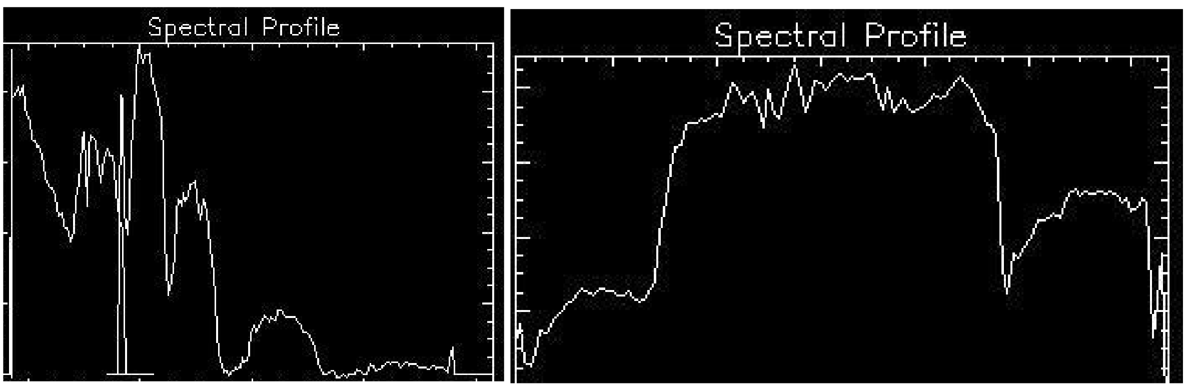


Figure 2: Methodology of the study

4. RESULTS AND DISCUSSION

Hyperion image processing was among the important works to enhance the information given in different spectral region of EMR. Out of 242 bands, only 164 were calibrated, remaining bands were not used as they were considered as bad bands due to no information or high signal to noise ratio (SNR). The dark vertical stripes in image was apparent, especially in the first few bands of VNIR (Visible Near InfraRed) and many SWIR (ShortWave InfraRed) bands, which were minimized by destripping. The image used for the study corresponds to the month of March, the end of winter. Some parts of the study area on the higher ridges of Mussoorie were affected by clouds and their shadow. However, the affected areas were removed by masking. The image was used for the atmospheric correction, which is important for reflectance measurement. Significant changes were observed in the atmospherically corrected image. The resultant spectrum of the vegetation after performing FLAASH was used for further analysis. The spectral profiles before and after atmospheric correction are shown in Figure 3. The image was geometrically rectified using L1T product of same sensor.



(A) **(B)**

Figure 3: Spectral profile before (A) and after (B) atmospheric correction

On the image, pure patches of Oak and Sal were identified and field work was carried out in the region. Sampling in 20 plots was done for each vegetation type. Enumeration of leaf and trees was done in each sampling plot. Distribution of sampling points are shown in Figure 1. N estimated from the field collected samples varied from 1.74% to 2.01% in Oak vegetation. Similarly, the foliar N concentration for Sal vegetation was from 1.83% to 2.72%. Foliar N concentration widely varied among species according to the contrasting phenological stages and functional types. Similar results were obtained by Singh and Singh, 2014 in the same region. The result from leaf count showed that Sal had less leaves than Oak. Average number of leaves for Oak was 9684789 ± 679977/0.1ha and for Sal it was 389324 ± 35168/0.1ha. Using the leaf mass and N %, content leaf N mass was calculated. Leaf N mass for Oak was 0.049 ± 0.001 t/0.1ha and for Sal it was 0.012 ± 0.005 t0.1ha.

Leaf N mass calculated from the ground data was correlated with the spectra derived vegetation index. Vegetation index was performed using ground spectra and image spectra as well. Different wavelength combinations were used for the NDNI. The wavelengths were selected based on the literature review. Where reflectance at 660nm, 760nm, 1510nm and 1680nm was found to be most suitable for nitrogen estimation. Reflectance at 1510nm is considered as sensitive for nitrogen absorption while rest were considered as reference wavelength. Correlation result obtained from the study is shown in Table 1 and Table 2 for Sal and Oak, respectively. The wavelengths were selected by the availability and less SNR in the band of Hyperion image. For Sal vegetation, correlation was found to be significant using wavelength combination for all the three indices, while it was highest for NDNI using simple ratio. Overall, NDNI (with log normalized) showed higher correlation than other two methods considering all the wavelength combinations. For Oak, wavelength combination at 1518nm and 1690nm showed overall good relation using image spectra, while it was not significant using spectra collected from ground. However, with log normalized NDNI, it was found to have significant correlation for both the spectra, ground as well from image.

Table 1: Correlation between NDNI and Leaf N Mass at various band combinations for Sal

Index	Source of spectra	1518:660	1518:760	1518:1690
NDNI (with log)	satellite data	0.618*	0.633**	0.597*
	field data	0.724**	0.487	0.773***
NDNI (without log)	satellite data	0.727**	0.514	0.438
	field data	0.707**	0.415	-0.05
NDNI (simple band ratio)	satellite data	0.742**	0.524	0.447
	field data	0.831***	0.385	0.48

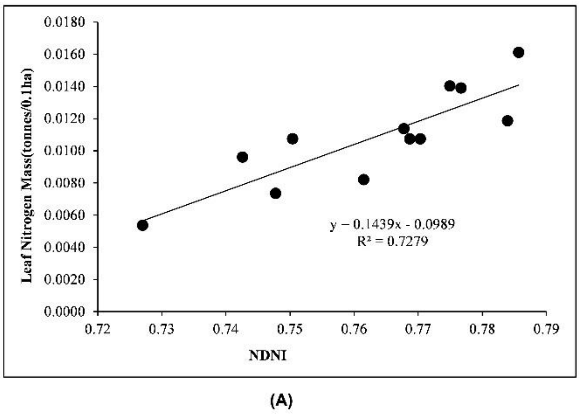
*Significant @0. 1%, **Significant @0.05%, ***Significant @0.01%

Table 2: Correlation between NDNI and Leaf Nitrogen Mass at various band combinations for Oak

Index	Source of spectra	1518:660	1518:760	1518:1690
NDNI (with log)	satellite data	-0.123	0.689**	0.737**
	field data	0.740**	-0.458	0.703
NDNI (without log)	satellite data	0.038	0.706**	0.752**
	field data	0.577*	-0.02	0.224
NDNI (simple band ratio)	satellite data	0.028	0.715**	0.755**
	field data	0.593*	-0.023	0.235

*Significant @0. 1%, **Significant @0.05%, ***Significant @0.01%

The spectral band that correlated highly with N concentration are similar to those found in other studies (Yoder and Pettigrew-Crosby,1995). In tropical forest foliage, protein-N has absorptions centered on 1510-1790 nm, but this region is also partly obscured by water absorption and is partially affected by variations in leaf structure and thickness. Nonetheless, a combination of the chlorophyll and Protein-N absorption features provides the strongest spectral correlations with leaf N concentration (Curran,1989). Thus the sensitive N indices related to Leaf N mass were identified for both the species. The regression analysis was done using the best wavelength combination for both the species. The coefficient of determination (r^2) was 0.73 for Sal and 0.82 for Oak. The regression model developed from this analysis is shown in Figure 4.



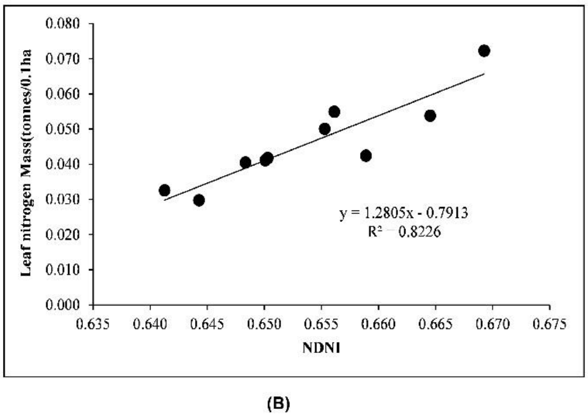


Figure 4: Regression plot between NDNI and Leaf Nitrogen Mass for (A) Sal and (B) Oak

This regression equation was used for the mapping of foliar N mass map of the study area (Figure 5). The average foliar N mass for Sal was estimated to be 0.123 ± 0.01 t/0.1ha and it was 0.485 ± 0.03 for Oak forest. Considering the total area (118.85 km^2) of the Sal forest in the study area, total foliar N mass of Sal vegetation was 1.5 Gg. Total foliar N mass of the Oak vegetation was estimated to be 1.9 Gg whose geographical area was 38.86km^2 in the study area. Many such studies have been done using Airborne AVIRIS data. Marie et al., 2003 demonstrated a similar potential for the space based Imaging spectrometer. Detection of canopy N within 0.5% by dry mass is the minimum necessary to distinguish among ecosystems (Schimel, 1995). Hyperion has a low SNR and a narrow usable spectral range, when compared to AVIRIS, yet the accuracy of space-based prediction is well within the limits to detect the important spatial patterns of canopy nitrogen over native forest landscapes.

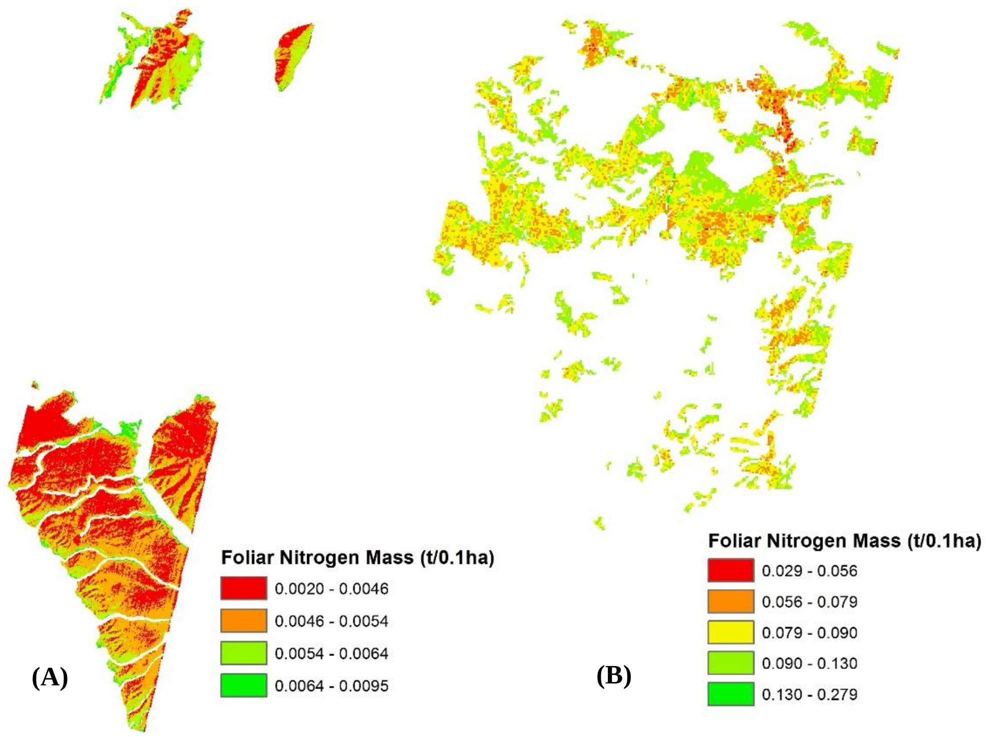


Figure 5: Foliar Nitrogen Mass map of (A) Sal and (B) Oak vegetation

5. CONCLUSION

The results of the present study revealed that hyperspectral data can be used for estimation of foliar N and leaf N mass from the forest canopies. It is recommended that the wavelength used in NDNI need to be modify according to the species under study and it can also depend on the sensor. As NDNI was developed and tested on the AVIRIS data, fine tuning is necessary to identify the exact wavelength at which absorption takes place. The modification in the vegetation index can be helpful in better prediction of the model. The present study does not take into account the relationship between canopy architecture (such as Leaf Area Index, leaf orientation and canopy gap fraction) and light distribution. Such a study will help in accurate prediction of canopy N. The foliar N mass map is very useful in the providing information about the productivity of the ecosystem and it can also be used as a replica of carbon sequestration potential map. To manage forest sustainably N map can be a significant input layer and with remote sensing technique it will be time saving.

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