DISCUSSION

The objectives of the present investigation are:

1. To develop spectral signatures for selected/dominant tree species
2. To describe distinct absorption pattern in the vegetation spectra of dry and wet season imagery by applying continuum removal spectra
3. To look at within species variation based on size and topography
4. To look at the importance of uniformity/homogeneity in patch size & phenology of vegetal cover in affective accuracy assessment for wet and dry season data.
5. To highlight the potential of Hyperion data in deciphering floor cover characteristics from soil in dry season.

Results are discussed under separate heads along with pertinent literature for supporting the observations. An attempt is made to draw conclusions from a holistic view. In this process few inferences are likely to come up again and again. Omissions would have given an incomplete canvas. Likely errors coming from the analysis of Hyperion data are mentioned in Appendix I.

4.1 Seasonal variability in two different Hyperion data sets

Results showed that the selected dates demarcated the vegetation of study area by phenology as vegetation was in different stages of senescence in the month of April, 2006 (dry season) and it was lush green due to seasonal change in the month of October, 2006 (wet season). The most striking difference between the images is the apparent increase in the abundance of green cover in the wet season. It is indicated by an increase in near-infrared reflectance at 854nm band. Growing season at SWS is from May – October coinciding with precipitation when trees have full green canopy. In dry season Shoolpaneshwar Wildlife Sanctuary (SWS) showed deciduous nature with different stages of senescence. Varying degrees of senescence in the dry season resulted in more spectral variability. The dry deciduous nature of the forests is responsible for low to moderate vegetation signal. Spectral characteristics of forest species are dependent upon phenological condition, chemical constituents present, moisture condition of soil and vegetation as well as external factors such as atmospheric interference, shadow, altitude, etc. Similarly, the reflectance properties of forest species are also influenced by the structural properties such as physiognomy, fractional coverage, plant height, crown diameter, association with other species and planting geometry. The spectral characteristics of vegetation are mostly affected by the quantity of pigments in the visible region, leaf cellular structure in NIR and leaf water content in SWIR of the spectra. Similar inferences were reported earlier (Demarez et al., 1999).

4.2 Reflectance spectra of selected tree species

A dynamic condition across tropical forests (SWS) and seasonal cycles (Dry season & Wet season) leads to subtle differences in tree species reflectance. Natural cycles such as leaf flush and senescence, as well as environmental factors affecting mineral nutrition, health, light availability, and water supply may contribute to changes in a species spectral signature over time or at a given position in the canopy (Carter, 1993). Variation in vegetation structural properties, such as the amount and architectural placement of the tissues within canopies, sharply impacts pixel-level reflectance (Myneni et al., 1989). Asner et al. (2000) reported the relative impact of canopy and landscape factors on pixel level reflectance which differed with plant composition and phenology. He also reported significant variation in vegetation type and condition, subtle level changes in pixel level reflectance variability all coming from high spectral resolution data. In this study phenological variations in the selected trees were clearly seen in the descriptive spectra of dry and wet season which are in confirmity with these findings. The seasonal parameter allows the discrimination between evergreen and deciduous tropical tree species. The deciduous species were present in different stages of senescence at the time of satellite path. In dry season, deciduous tree species drop their leaves and in wet season deciduous species are in fully flushed condition. Thus the size and biochemical composition of leaves vary through the season and altering the leaf reflectance among deciduous species. Whereas, for evergreen species the temporal changes of reflectance may be less than deciduous ones. Analogous results were reported by Kokaly et al. (2003).

Earlier, Lumme (2004) considered descriptive spectra as a pure endmember. In this study descriptive spectra obtained were distinct for each species. A visual comparison of the spectral curves for each species revealed similarities in pattern whether it is from dry or wet season. This is because all vegetation contains same basic constituents, including chlorophyll and other light – absorbing pigments, water, proteins, starch, waxes and structural biochemical molecules such as lignin and cellulose (Elvidge, 1990). Portigal et al. (1997) reported that the reflectance of vegetation from different species is highly correlated due to their common chemical composition. Therefore, the spectral separability of vegetation presents challenges because the number of independent variables that influence the spectra is small (Price, 1994). However, Ustin et al. (1993) reported that the relative concentrations of photosynthetic pigments and the presence of accessory pigments does vary among taxa, where the depths and widths of pigment absorption troughs, and the position and magnitude of reflectance peaks can be quite different among species. The reflectance from descriptive spectra of these 7 selected tropical tree species showed variation in the strengths and shapes of the chlorophyll and leaf water absorption features. There is a distinction in the spectral curve of each species.

Results showed that reflectance spectra of 7 tropical tree species had characteristic pattern in dry and wet season. Selected 7 tree species showed different vegetational signals in the months of April and October. Roberts et al. (2004) reported that in the wet season, low VIS reflectance caused by chlorophyll absorption and other pigments, high NIR reflectance due to multiple scattering within the leaf structure, weak NIR water absorption features at 980 nm and 1200nm, and moderate reflectance in SWIR-I and SWIR-II with peaks at 1650nm and 2200nm caused by dominant water absorption features at 1400, 1900 and 2700nm. In this study, similar features were observed in the descriptive spectra of wet season. Spectra obtained for wet season data displayed low variability compared to that of the dry season and showed consistency. Reflectance characteristics in wet season demonstrate that the spectra exhibit minimal separability in terms of magnitude in the VIS wavelengths. VIS spectral variability among species is low due to strong absorption by chlorophyll (Cochrane, 2000; Poorter et al., 1995). In SWIR1 and SWIR II, water absorption tends to obscure other absorption features produced by biochemical constituents such as lignin and cellulose (Asner, 1998). Similar inferences can be drawn from the spectra of the present study.

In dry deciduous type of forest, as soil water balance decreases, phenological variations become more pronounced in the tree species. Due to the phenological variation the size of canopy and biochemical components vary affecting the leaf reflectance. Species with different phenological conditions could show different spectral signatures. In this study, as the leaf senesces, lower pigmentation greatly reduces the amount of absorption throughout the VIS, thereby increase reflectance. Individuals of selected 7 tree species had very low density of crown foliage in the dry summer season. With fewer or senescenced leaves in the crowns of *Tectona, Dendrocalamus* and *Wrightia*, there was lower NIR reflectance relative to leaf-on season. Similar results were observed by Clark et al. 2005. Earlier Lewis et al. (2000) reported that as the plant dries out the near infrared shoulder (1300-1400nm) collapses and absorptions due to cellulose and lignin becomes more prominent at 1700-1800nm, 2000-2200nm and 2260-2380nm. In this study spectra of deciduous trees in dry season showed similar pattern. In wavelength longer than 1100nm, the dry vegetation showed much higher reflectance compare to green vegetation. This is in confirmity with the findings of Lee et al. (2005).

4.3 Application of continuum removal spectra to describe distinct absorption pattern in the vegetation spectra of dry and wet season imagery

In order to identify a spectral feature by its wavelength position and shape, it must be isolated from other effects, such as level changes and slopes due to other absorbing materials (Clark et al., 2003). The continuum removal algorithm removes the effects of these other absorptions in the spectrum (Clark, 1999). Kokaly et al. (2003) have used continuum removal spectra to isolate specific absorption features and remove the effects of changing slopes and overall reflectance. The apparent depth, or strength of an absorption feature relative to the continuum is dependent on the intrinsic absorption strength, the grain size and abundance of the material, as well as the abundance, absorbing nature, and grain size of the other material mixed with the sample (Clark & Roush, 1984). Results of continuum removal spectra for selected tropical tree species showed distinct absorption features in VIS and SWIR regions of the spectrum. Separation is very clear at VIS and SWIR-II wavelengths. In this study, chlorophyll absorption features are stronger in wet season and weaker in dry season. Within groups such as dry and green vegetation spectra, there is considerable variation in the shapes and features. These features can be easily extracted by continuum removal spectra. This kind of diagnostic absorption features are unique to particular materials in shape and are usually concentrated in limited ranges of wavelength by type of absorption. This corresponds to the finding of Kokaly et al. (2003) where he worked on different forest cover types using continuum removal spectra. In wet season, the water absorption features at 980nm were observed due to amount of high leaf water content in the forest vegetation. Similarly, Kokaly et al., (2003) also found water absorption features for forest vegetation with a distinct band at 982nm compared to non forest vegetation where he reported broad flatter water absorption features from 962-982nm.

Continuum removal spectra have also been used to discriminate green and dry vegetation (Lee et al., 2005). In this study, the continuum removal spectra clearly showed several distinguishable absorption features. Spectra of trees like *Pongamia, Mangifera* and *Ficus* from dry season showed chlorophyll absorption features in the VIS region of the spectrum due to their phenological condition. *Pongamia* clearly showed relatively maximum chlorophyll absorption depth. Whereas deciduous species like *Tectona* and *Dendrocalamus* demarcated lesser chlorophyll absorption features. In the region of SWIR II, *Dendrocalamus* and *Tectona* showed maximum absorption whereas *Pongamia* showed minimum absorption denoting that different biochemical features become more pronounced in dry condition. This is in accordance with earlier studies (Lewis et al., 2000) who worked on dry plant materials describing the importance of SWIR-II for chemical characteristics. Spectral characteristics of various surface conditions during the dry season are dependent upon soil type, chemical constituent of dry vegetation, and moisture conditions of soil.

4.4 Intraspecies spectral variability

Within species variation was distinctly observed for *Tectona* as it is dominant in the study area occupying larger area. The reflectance spectra of different pixels of *Tectona* showed variation based on the strengths of canopy closure, size of the trunk, slope of area. Variations in the reflectance values are due to physiognomy of trees and also for topographic change. Many other factors such as plant stress, disease, nutrients and moisture level can also affect the reflectance of tree leaves. There is also variation in reflectance data in dry condition as the woody material, litter of the trees and soil will reflect differently than green leaves. Few studies have examined that the multiple factors can introduce spectral variance within tree crowns or species due to reflectance, absorption, transmission properties of leaves and wood, viewing geometry, host of other environmental factors such as microclimates, soil characteristics, precipitation, topography and soil moisture (Cochrane, 2000; Portigal et al., 1997). In addition, foliage age (Roberts et al., 1998), position in the canopy (Danson, 1995), chlorophyll content (Zarco-Tejada et al., 2003), forest vigor (Luther & Carroll, 1999) and the presence of lianas (Castro-Esau et al., 2004) have been shown to cause substantial variation in the spectral response of some species. In the tropics, colonization by leaf pathogens may also change the spectral response, especially among older leaves (Roberts et al., 1998). It is also reported that the relative concentrations of photosynthetic and accessory pigments will also vary within a plant species because of genetic variation, seasonal cycles, and stage of growth, health, or environmental conditions (Alcoverro et al., 2001; Longstaff & Dennison 1999; Dawson & Dennison 1996; Pe´rez-Llorens et al., 1994). All these are largely responsible for the variations seen in the spectra.

Variations are more in the spectral reflectance of dry season imagery when compared to wet season imagery. Variations can be seen in the spectral reflectance of *Tectona* of different girth classes growing in similar areas. This indicates that hyperspectral data is useful in demarcating trees of same species according to their size (Christian & Krishnayya, 2007). This could be of use in biomass estimation. As green leaf canopy is almost absent, developed curves can be attributed to be solely due to wood (trunk and large branches) of *Tectona.* This can be of use in forest mensuration. Additionally, in dry month imagery the difference in the reflectance values of *Tectona* from different pixels is maximum in SWIR-1 region of the spectrum. Differences in continuum removal absorption spectra are attributed for factors such as lignin and water content indicating that there might be reason to expect spectral differences among species due to different chemical make-up (Van Aardt & Wynne, 2001). Hence, this region of spectra appears to be more suitable for discrimination at dry season by using chemical characteristics.

ANOVA performed on the results showed that the differences seen amongst reflectance spectra of different girth classes are significant (α=.01) for both the data sets. There is a negative correlation between girth of the *Tectona* tree and corresponding reflectance spectra from dry month imagery. On the contrary, there is a positive correlation between girth of the *Tectona* tree and corresponding spectra in wet season. The fact is that the high degree of correlation exists in green foliage reflectance data (Korobove and Railyan, 1993), this aspect may not be valid for dry season vegetation where significant amount of leaf litter and bare soil are often present.

Continuum removal spectra of wet season showed maximum chlorophyll absorption in the 50-90cm girth class, where as minimum chlorophyll absorption in the spectrum of 35-60cm girth class. Earlier Kokaly et al. (2003) have reported that it is difficult to distinguish age classes from one another spectrally based only on the chlorophyll absorption feature. On the contrary present results showed differences in the depth of chlorophyll absorption features based on girth classes.

4.5 Species level discrimination using Maximum Likelihood algorithm

In order to look at amongst species variability, descriptive spectra have been used for 7 different selected tropical tree species with varying levels of senescence using dry season imagery. Dry month imagery have shown to reveal greater differences among vegetation types, because of variations in tolerance to water stress and differences in soil moisture availability (Whitmore, 1998). To evaluate variability, spectral metrics which describe reflectance shape and amplitude (Price, 1994) were calculated. Cochrane (2000) has observed within and among species variations and compared the spectra of different species using the discrimination metrics. From the results it was observed that each species had a range of D and θ values, due to the variability inherent in each species. Consequently, it is only possible to predict species which are more likely or less likely to be spectrally confused with *Tectona*. From a comparison of the D value in the given table, it would be expected that *Dendrocalamus* and *Madhuca* would be similar to *Tectona*. *Tectona* and *Dendrocalamus* are in deciduous condition in dry season which is the reason for similarity present between them. However, θ values showed that *Mangifera, Pongamia*, *Dendrocalamus* and *Ficus* are in different shape from *Tectona*. From the two measures, it could be shown that evergreen trees like *Mangifera, Pongamia* and *Ficus* are spectrally dissimilar to *Tectona*. Variation can be seen in D and θ values with reference to different stages of senescence. This is analogous to the results of Danson (1995) who reported significant differences in spectral reflectance as a function of position in the canopy. ANOVA performed also showed that the differences seen amongst descriptive spectra are significant (α=.01). Thus distance measurements (D & θ) and ANOVA of descriptive spectra are suitable in confirming the separability.

Foliage cover variation within the deciduous forest canopy, where senescent plant material was relatively abundant, resulted in only slight variation in the VIS and SWIR, but greater variation in the NIR (Asner et al., 2000). In studies investigating the discrimination of terrestrial plant species, the largest differences in reflectance have been recorded in the near infrared (NIR) and shortwave infrared (SWIR) wavelengths (Borregaard et al., 2000; O'Neill et al., 1990). In this study slight to significant variations are seen at VIS, NIR, and SWIR-I regions of spectrum. A good number of studies have recorded the differences in the spectral reflectance of terrestrial plant species in the visible wavelengths (Datt, 2000; Yu et al., 1999; Kumar & Skidmore, 1998; Gong et al., 1997). Further, SWIR variability among species may be related to two factors: overall differences in leaf water concentration that affects the expression of water absorption features at 1400, 1900 and 2700nm (Roberts et al., 2004), and ligno cellulose absorption features that may be expressed when high fractions of dry vegetation are exposed to the sensor (Asner, 1998; Curran, 1989). As spectral characteristics observed in this study are similar in nature, analogous inferences can be made in this study. Blackburn (1998) has reported variation in the slope of red edge and in NDVI due to the seasonal variation in the spectral characteristics of deciduous tree canopies. Dennison & Robert (2003) have reported that seasonal variation leads to finer level of spectral detail in hyperspectral data which allows classification of vegetation species. Similar observations are seen in this study. Examination of descriptive spectra for different tropical tree species in senescent condition indicated that the Hyperion data provides many possibilities for separating vegetation categories.

4.5.1 Derivative analysis

The first derivatives of descriptive spectra were computed along the red edge and were used as a measure for senescent vegetation. A good number of studies demonstrated derivative for analysis as a common tool to suppress the effects of background, brightness differences and enhance subtle spectral difference amongst spectra (Fung et al., 1999; Martin et al., 1998; Shaw et al., 1998; Bubier et al., 1997; Gong et-al., 1997; Martin & Aber, 1997b; Niemann, 1995). In this study the first derivative measures the slope change from the red to NIR portion of the spectrum and is minimally affected by soil background and may serve as an indicator of senescence in selected tropical tree species. The double-peak feature was observed on the first derivative reflectance near 701nm and 732nm in the red-edge region. This is in accordance with the findings of Boochs et al. (1990) and Lamb et al. (2002) where they have observed REP values near to 700nm and 735 nm and mentioned that REP (Red Edge Position) values near to 700nm is due to low chlorophyll concentration while high chlorophyll concentration influence REP values near to 735 nm. Several other studies have revealed the existence of this double-peak feature in the first derivative of contiguous spectra (Clevers et al., 2004; Smith et al., 2004; Zarco-Tejada et al., 2003). Experimental and theoretical studies show that REP shifts according to changes of chlorophyll content (Belanger et al., 1995), LAI (Danson & Plummer, 1995), biomass and hydric status (Filella & Penuelas, 1994), age (Niemann, 1995), plant health levels (Vane and Goetz, 1988), seasonal patterns (Miller et al., 1991), leaf developmental stage, leaf layering or stacking and leaf water content (Horler et al., 1983). The observations and conclusions of this study broadly go together with the findings mentioned above.

It has also been shown that chlorophyll is not the only factor that determines the shape of the red edge peak in the reflectance derivative curve. Horler et al. (1983) and Boochs et al. (1990) defined two components to be responsible for the position and shape of the red edge peak: chlorophyll content, that causes changes around 700 nm, and scattering properties, that affect the spectrum at longer wavelengths. These scattering effects are linked to the total biomass. Water stress is another factor that could also affect the shape of the red edge peak in the first derivative curve because water stress affects near-infrared reflectance through structure which results in scattering changes (Penuelas et al., 1993b). Observations of this study for senescent vegetation are in confirmity with these findings.

When a plant is healthy with high chlorophyll content and high LAI, the red edge position shifts toward the longer wavelengths; when it suffers from disease or chlorosis and low LAI, it shifts toward the shorter wavelengths (Pu et al., 2003). Difference in the REP values from derivative spectra for *Pongamia* and *Dendrocalamus* species are in confirmity with this finding. When the trees are in-leaf, leaves are the dominant scene elements, and the maximum slope is positioned at around 726nm (Blackburn & Milton, 1995). In present study similar REP values were observed with evergreen species (723.03-725.29). In present study, different REP values for selected tropical tree species have also shown usefulness of the four point interpolation technique for species level discrimination. It is reported that the linear approach is computationally simple, robust, the most practical and suitable method for extracting the REP from hyperspectral data when compare to other methods, as only four bands and simple interpolation computations are needed (Clevers et al., 2002). The effectiveness of the four-point interpolation also used for extracting REP was also demonstrated by Danson & Plummer (1995).

4.5.2 Species level classification

This study explored classification schemes at species level using Maximum likelihood classifier (MLC) for dry season imagery. MLC is a well known supervised classifier which is a standard in remote sensing (Richards & Xiuping 1998) and is also used for pixel-based hyperspectral classification (Clark et al., 2005, Salvatori et al., 2003). Supervised classification schemes are often stymied by the large dimensionality of hyperspectral imagery (Clark et al., 2005). Jackson & Landgrebe (2001) have reported that with ML classifier in particular, within-class covariance matrix can be poorly estimated, when there are few training samples relative to the data dimensionality, leading to a decrease in classifier performance called the Hughes Phenomenon (Jackson & Landgrebe, 2001). Hence, the use of ML is limited for hyperspectral remote sensing of forested areas because image dimensionality is high while training data are expensive or difficult to acquire. A common solution to this dilemma is to reduce data dimensionality through spectral feature (i.e., band) selection. Data reduction is also necessary for determining correlation between adjacent wavelengths in a sample (Hoffbeck & Landgrebe, 1996). Further Landgrebe (2003) reported that the hyperspectral data tend to have a high level of redundancy, indicating that a lower dimensional representation may be more efficient. Given the availability of a limited number of samples versus the large number of variables present in the hyperspectral data set, the reduction of data dimensionality is critical. In this context, scientists have reported the importance of band selection to reduce dimensionality (Van Aardt & Wynne, 2001). Present study tried to find sensitive wavelength bands that can be useful for classification of tropical trees as band selection is a necessary analytical step to isolate the most important bands for reliable classification. In studies incorporating low concentrations of pigments, as found in early immature and later senescent leaves and canopies with low leaf area and canopy cover, reflectance at wavelengths corresponding the centre of major absorption features are most sensitive to pigment concentrations (Sari et al., 2005; Blackburn, 1998). Keeping this and vegetal cover of the study area in mind band selection for classification was finalized for dry season imagery. First derivative spectra were used in this study (Van Aardt & Wynne, 2001; Gong et al., 1997). The band selection scheme for pixel spectra identified important bands which are coming from red edge regions and SWIR I regions.

Previous work (Binaghi et al., 2004) on the feature selection procedure for hyperspectral MIVIS data classification has shown that the red edge region and part of SWIR (1.500–1700 nm) are useful spectral regions for vegetation mapping. These results are physically justified by the foliar pigments absorption behaviors. Differences in foliar chemistry are determinant in vegetation spectral discrimination; Martin et al. (1998) showed the importance of SWIR for nitrogen and lignin detection and Zarco & Miller (1999) underlined how the red edge region can describe the differences in photosynthetic pigments. The latter showed that a classification based solely on chlorophyll content variation, derived by REP analysis, can be useful in forest species detection. The present study reaffirms the importance of using band 700nm (red edge region) which is showing positive peak in the first derivative spectra for all selected tropical tree species. Similar observations were also made in the findings of Shafri et al. (2006) who observed that REP can effectively be used to classify and distinguish different vegetation types and ages. Lambert et al. (1995) clearly demonstrated that SWIR I (1300- 1900nm) bands show the greatest ability to discriminate between lightly and heavily damaged forest classes. Similar observations can be seen here in derivative spectra at near 1396nm and 1736nm, coming from SWIR I region of the spectrum. Present study also re-affirms the study of Dawson et al. (1999) who have used the absorption wavebands around 1400nm and from 1900 to 1950 nm, because they coincide with water absorption features.

Accuracy levels for different species range from 40 % to 80.0% indicating the potential of Hyperion imagery for discrimination of tropical trees. The potential of first derivatives were observed in species level discrimination. Results are in accordance with the findings of earlier scientists who observed that the use of first derivatives has shown to improve tree species classification over the use of reflectance spectra (Van Aardt & Wynne, 2001; Gong et al., 1997). Van Aardt & Wynne (2000) reported that the derivatives of the spectral profiles were recommended for classification, as they were relatively insensitive to variations in illumination intensity caused by angle, cloud cover and topography. Here, the use of derivative techniques to enhance spectral differences between and within tree species proved to be very effective, contrary to findings by Fung et al. (1999) and Zhang et al. (2006).

Variation in site conditions, microclimate, as well as soil moisture could have caused inconsistency in classification. There was interclass confusion between *Madhuca* and others. As mentioned in among species variability, this confusion is attributed to the deciduous phenology of these species which had very low crown LAI and similar spectral properties. Litter, soils are also more likely to be exposed to the sensor in low LAI crowns, and spectra from these components could dilute tree species spectral differences. Similar observations were also made in the findings of Clark et al. (2005) who reported that bark lichen, epiphytes, and understory plants are also more likely to be exposed to the sensor in low-LAI crowns, and spectra from these components could dilute tree species spectral differences. Present study presumes that misclassification recorded for other trees could be either because of phenological similarity and / or dominance of background reflectance.

These are bound to be seen in tropical areas where vegetation is highly heterogeneous. Accuracy levels are high for *Tectona* and *Dendrocalamus* mainly because of their large distribution and homogeneity. More producer's accuracy for *Tectona* is encouraging as it has important ecological and economical functions. Supervised classification also showed clear discrimination in size classes of *Tectona*. This could be of great use in the determination of biomass estimation (Christian & Krishnayya, 2007). This indicates that Hyperion data can be useful in identifying different size classes of trees occurring as pure patches with larger area of occupancy. Keeping in view of the data used (spaceborne Hyperion data), complexity and patchy distribution of vegetation, at the study site, the OAA is fair enough for species level classification of tropical trees in different phenological condition. Analogous conclusion was drawn by Thenkabail et al. (2004). These results are encouraging since present space-borne data suffers from multiple factors that could confound species discrimination, such as mixed pixels in training and testing data, variable illumination and viewing geometry, and noise introduced by atmospheric conditions and non-target biological organisms. However, one major advantage of contiguous hyperspectral bands is their continuous description of spectral space, allowing measurements of the shape and position of key spectral features, such as red edge features, liquid water absorption features in NIR and SWIR. Phenology is an important factor in the discrimination of tropical tree species. Here suitable date to discriminate tropical tree species based on phenological condition showed similarity to the findings of Nagendra, (2001) where it was mentioned that suitable dates should be selected when species are at different phenological stages. This kind of information is very useful for effective forest management.

4.6 Species level discrimination using Spectral Angle Mapper (SAM)

Results from wet season image showed the possibility of discrimination of tropical tree species using spectral angle mapper algorithm of spectra from 196 bands, spectra of different spectral areas (partition analysis) and spectra coming from Minimum Noise Fraction (MNF) transformed data. The MNF transformation consists of two consecutive principal component analyses. The first transformation, based on an estimated noise covariance matrix, decorrelates and rescales the noise in the data. The second step is a standard principal component analysis based on the results of the first step. Only the first 15 MNF channels were used in the subsequent steps as they contained most of the information of the hyperspectral dataset. In a similar manner MNF transformation was performed by Buddenbaum et al. (2005) for data reduction and enhancement. In this study the data processing showed the advantages of MNF transform followed by the development of Pixel Purity Index (PPI). These transformations enabled to narrow down sizeably the actual pixels to be classified. It also helped in the extraction of endmember spectra from field-based measurements for each species. Earlier it is reported that endmembers are usually selected either from the image data (Wessman et al., 1997) or from spectral libraries built from field surveys (Roberts et al., 1998). Here image-based endmembers were considered as ideal because they are drawn from a population of data points to be analysed, which increases the likelihood that image pixels will be deciphered using endmembers coming from images. Observations of this study are in the line with the findings of Li et al. (2005) who used the first 15 MNF band derived image for the determination of endmembers thereby removing the majority of bands that exhibit significant noise. Plourde et al. (2007) also used PPI to the MNF bands in order to find the most spectrally pure pixels.

Spectral Angle Mapper (SAM) is an automated method that permits rapid mapping of spectral similarity of reference spectra to unknown spectra. The spectral angle between two spectra has been used extensively in the hyperspectral remote sensing community to quantify the similarity between spectra from different tree species (Clark et al., 2005; Cochrane, 2000; Price, 1994). SAM classification with 196bands (full-spectra) of Hyperion data gave 51% OAA for the 5 tropical trees selected. Obtained OAA is fairly valued looking at the pattern of vegetal cover and also of the sensor used. Similar values of OAA were reported earlier by Clark et al. (2005) and Lumme (2004) by using airborne data. Present study concludes that OAA recorded is fine as it is coming from a spaceborne sensor. Partition analysis across the spectrum was done for three regions (VIS-NIR, SWIR-I, SWIR-II) instead of four regions as reported by Clark et al. (2005). VIS-NIR region was taken together to give emphasis for red edge variations as the canopy is lush green. OAA was maximum at VIS-NIR indicating its superiority in classification. In this study tree crowns are with green foliage having the highest chlorophyll content in a growing period. Hence VIS-NIR region gave a better canopy level separability. Importance of VIS-NIR region was earlier highlighted for vegetal analysis (Thenkabail et al., 2000; 2004; Thenkabail, 2002; Martin et al., 1998; Gong et al., 1997) and also for subtropical tree species (Fung et al., 1999). Van Aardt & Wynne (2001) emphasized the usefulness of the visible spectrum for species and taxonomic group discrimination, utilizing the subtle differences not detectable by the human eye. The NIR region was particularly useful in pixel-scale species discrimination, especially with sunlit samples (Clark et al., 2005). Present results are in confirmity with these reports. OAA for other two regions (SWIR-I & II) was less. This is analogous to the findings of Van Aardt & Wynne (2001) who reported poor representation of SWIR-II region during the discrimination of six southern tree species. In contrast, the results of Clark et al. (2005) showed better crown scale separability at SWIR-II. This is substantiated by Martin et al. (1998) using AVIRIS data. SWIR-I & SWIR-II regions are related to the expression of water absorption features (Roberts et al., 2004) and ligno-cellulose absorption features. Lush green vegetation could have minimized spectral separability at SWIR-I & II.

Present study observed advantages in classification using MNF bands. Similar advantage in classification using MNF bands is reported (Chen et al., 2007). Higher SNR (Signal to Noise Ratio) values are mainly responsible for sharper and distinctly classified images. SAM showed the highest accuracy (59.57%) for spectra of 1-10MNF bands. Similar OAA values were reported by Buddenbaum et al. (2005) for classifying age classes of Douglas fir and Norway spruce using SAM as a classification algorithm. Higher accuracy using MNF band combination indicated the potential of MNF transformation to increase classification accuracy of tropical trees by reducing data dimensionality. The overall classification accuracy obtained in this study, particularly when using reference spectra of 1-10MNF bands (59.7%), is encouraging. SAM proved to be a good algorithm for classifying tropical trees. On the contrary, Clark et al. (2005) have reported that the SAM classifier was the least successful of the classifiers, regardless of the spatial scale or spectral region considered.

Homogeneity in vegetal cover is a critical aspect for classification in tropical areas. The study area has an interesting distribution of vegetation. Of the ~ 127 tree species, *Tectona* and *Dendrocalamus* are the most dominant having large homogenous patches of sizes 100mX100m and 50mX80m respectively. In each sample plot of *Tectona*, density is 75 trees with the dbh of 0.3m-0.8m and spread of the canopy of individual is 1.2mX1.5m with a height of 6-8m. In each sample plot of *Dendrocalamus*, 33-37clumps are available with 25-80 stem density and spread of the canopy of each clump is 2mX3m with the stem height of 4-5m. This is aptly reflected in the

OAA figures where *Tectona* and *Dendrocalamus* showed higher accuracies. *Tectona* had the highest accuracy level because of the kind of distribution (Figure 1). *Dendrocalamus* had a different pattern of distribution and accordingly accuracy levels are different. The spread in *Dendrocalamus* is relatively less with dissected appearance giving way to the influence of background radiation. Distribution of all other tree species is highly heterogeneous. Like in any tropical area heterogeneity in species distribution is unique to the study area. Other species have heterogeneous distribution not even occupying a 40mX40m plot. Accuracy assessment levels for *Mangifera, Madhuca,* and *Ficus* are modest owing to their pattern of occurrence. At most of the quadrats laid their occupancy ranged between 50-65%. Heterogeneity in vegetal cover has largely influenced the accuracy assessment. Analysis of specific spectral regions, spectra of MNF bands with high SNR values fared better as compared to that of entire spectrum. *Mangifera* showed more accuracy. This could be because of large girth class (1.55-3.2m) and spread of the canopy (21mX25m). Here also crown shape (Figure 1) influenced the classification. Better spread of canopy as seen in *Mangifera* allowed it to fare better. With the reported densities for *Tectona* and *Dendrocalamus*, Hyperion is found to be an appropriate sensor for monitoring.

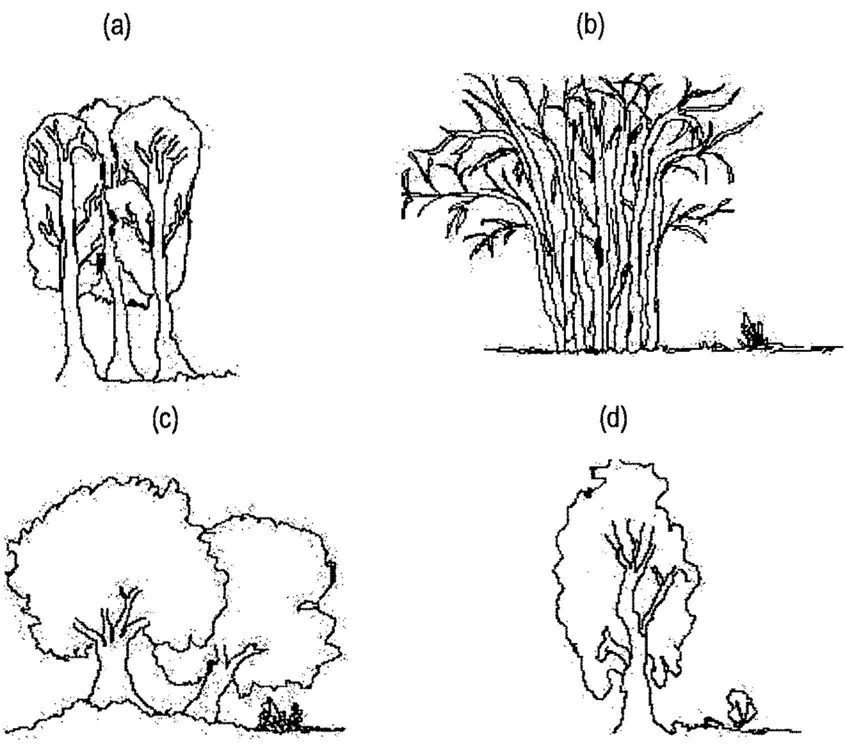

Figure 1: Canopy shapes of (a) *Tectona grandis*, (b) *Dendrocalamus strictus* (c) *Mangifera indica* (d) *Madhuca indica*

4.7 Forest floor cover studies

Results mentioned highlighted the potential of Hyperion data in deciphering floor cover characteristics in dry season. During dry season, the dominant factors were soil and litter reflectance. This period is suitable to discriminate bare soil from litter layer. Descriptive spectra of 3 floor cover types and one of bare soil are distinctly separable. It has been said that the reflectance spectra of bare soil could be distinguished from the other surfaces covered by dry vegetation during the leaf off season (Lee et al., 2005). Spectral characteristics of litter during dry summer month are influenced by different thickness and chemical constituents, exposed barren soil and moisture content (Lee et al., 2005; Roberts et al., 2003). In this study it was observed that species like *Tectona* and *Dendrocalamus* showed highest leaf fall in the month of March/April. Other species such as *Terminalia crenulata, Anogeissus latifolia, Garuga pinnata* and *Bridelia retusa* showed varying degrees of leaf fall. The importance of Cover Type was earlier described (Keane et al., 2002). It was reported that litter fall and branch fall properties tend to create distinctive floor characteristics (Brown & Bevins, 1986). Descriptive spectra of the 4 cover types mentioned here are in confirmity with these findings.

Results showed variations in litter reflectance due to different thickness. This helps in looking at the load factor of litter for a potential forest fire (Christian & Krishnayya, 2008). Asner et al. (2000) observed that litter reflectance variability contributed significantly in the VIS and part of the NIR regions. In this study litter reflectance variability was the lowest in VIS and highest in SWIR II region of the spectrum. These results were similar to those found for the Texas data set (Asner et al., 1998a). It is reported that VIS region was highly sensitive to an increase in canopy litter (550-700nm) (Asner, 1998). The wide ranging litter optical values are primarily due to differences in residual water content as well as species specific differences in lignin and cellulose concentration (Asner & Wessman, 1997). The lower water content in litter relative to fresh leaf material allows these organic chemical features (lignin ~2380nm) to emerge in the spectra (Jacquemoud et al., 1996). Analogous observations were observed in this study. Results also showed that the altitude of the terrain has an influence on the reflectance of litter. This is indicative of the importance of altitude variation in hyperspectral study.

Dry vegetations are spectrally very similar with soil in VIS and NIR wavelength (Daughtry et al., 2004; Streeck et al., 2002). Lewis et al. (2000) also observed positive correlation of dry plant litter with exposed bare soil. From results it was observed that all four categories showed similar pattern in NIR and SWIR region with slight variation in VIS region. This at times is not sufficient to discriminate different types of forest cover from soil. In order to differentiate them better the same had been plotted as continuum removal spectra.

As mentioned earlier, continuum removal spectra were used to isolate absorption features and to discriminate dry-green vegetation from soil (Lee et al., 2005; Kokaly et al., 2003). Other effects, such as signal to noise ratio, atmospheric effects and background noise, were reduced by continuum removal and normalization of band depths (Kokaly and Clark, 1999). Asner et al. (2000) reported the overall shape of the reflectance spectra, which incorporates a suite of local absorption features, makes the spectra of leaf, wood, litter and soil surfaces highly distinctive. In this study the continuum removal spectra clearly showed several distinguishable absorption features. The predominant absorption features are found in visible (500-690nm) and the SWIR-II (2050-2400nm) wavelengths where discrimination can be easily done. In past studies, scientists worked on dry plant materials described the importance of SWIR-II for chemical characteristics (Asner & Lobell, 2000; Lewis et al., 2000). In this study all four floor covers can be easily discernable in the SWIR-II region of the spectrum. Analogously to discriminate plant litter from soil Daughtry et al. (1996) developed a three band spectral index based on the depth of the lingo-cellulose absorption feature at 2100nm. He reported that the absorption in plant litter at 2100nm is most likely due to cellulose, hemicellulose, lignin and other structural components. The spectra of soils show no absorption at 2100nm. Observations from continuum spectra in this study are in confirmity with these findings.

Accuracy levels for different species range from 40 % to 87.5% indicating the potential of Hyperion imagery for discrimination of cover types. Hyperion demonstrated good capability for separating spectral signals from bare soil and dry plant litter. *Tectona* was also well mapped by Hyperion with a high producer's and user's accuracy.