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ESTIMATING LEAF AREA AND ABOVE-GROUND BIOMASS OF FOREST REGENERATION AREAS USING A CORRECTED NORMALIZED DIFFERENCE VEGETATION INDEX

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ABSTRACT

The objective of this study was to investigate the regression relations between vegetation indices derived from remotely-sensed data of single and mixed forest regeneration plots. Loblolly pine (*Pinus taeda L.*) seedlings, sweetgum (*Liquidambar styraciflua L.*) seedlings and broomsedge (*Andropogon virginicus L.*) grass were arranged in a factorial combination addition series experiment and replicated four times in a randomized complete block design. The remotely-sensed data were obtained using the Barnes Multiband Modular Radiometer (MMR) and a 35 mm camera between 26 June and 6 July, 1990. The normalized difference vegetation index (NDVI) and the ratio index (RI) were computed using the bidirectional reflectance factors obtained with the MMR sensor. Color 35 mm slides were used to independently estimate percent vegetative cover and percent bare soil exposed to the field of view of the radiometer. These data were used to generate a corrected normalized difference vegetation index (CNDVI) which alleviated the effect of bare soil exposed to the radiometer.

The relationships among the vegetation indices (VIs) and leaf area (LA) and above-ground biomass (BIO) in the single and mixed forest regeneration plots were quite variable. The best relationship between LA and BIO achieved among the spectrally-derived vegetation indices was obtained with the CNDVI, which generated prediction equations that accounted for over 82 percent of the variability from the single loblolly and sweetgum plots. The relationships and amount of variability explained among the Vfs and LA and BIO decreased in the plots that contained two or more species. These data show the importance of correcting for bare soil interference to spectrally-derived VIs.

INTRODUCTION

This study was a continuation of efforts aimed at evaluating relationships among radiometrically generated vegetation indices (VIs) and vegetation parameters on young pine regeneration areas (Brooks et al., 1989; Miller and Coleman, 1992). It was anticipated that proven relations with reflectance and leaf area of agronomic crops and mature forest stands would provide some insight into the intricate questions of quantifying inter-crown shading, needle arrangement, and degree of light scattering within the crown of young forest plantations. This study focus on regeneration areas and the problems associated with bare soil influence on spectral reflectance data used in generating VIs.

Phytomass. leaf area index (LAI) and percent plant cover are invaluable plant community parameters required by plant scientists and land managers in routine managerial activities. The critical need in forest vegetation management research is a practical means of estimating these parameters for crop trees and competing vegetation in young pine plantations. Remote sensing of solar reflectance using multi-channel radiometers. similar to those of the Landsat Thematic Mapper (TM) sensor. has been effective in estimating these parameters for some agronomic crops and range situations. The objective of this study was to investigate *the* regression relations between spectrally-derived vegetative indices and vegetative parameters of single and mixed regeneration plots of loblolly pine seedlings, broomsedge grass, and sweetgum seedlings.

Few studies have attempted to apply spectrally-derived vegetative indices to the forest environment as compared to studies involving agronomic crops and herbaceous cover types. This may be attributed to the high degree of variability in the results that have been achieved when investigating forest stands. Despite the success of several investigators who managed to generate adequate predictive relationships (Gholz et al.. 1991; Spanner et al., 1990: Herwitz et al.. 1990; Punning et al.. 1989; Sader et al., 1989; Danson, 1987; Running et al., 1986; Badhwar et al., 1986a. 1986b; Jensen and Hodgson. 1985). widespread use of this technology has not occurred. This can be attributed to several factors; however, the one factor most prevalent according to Gholz et al. (1991) is the inability of these relationships to evaluate the seasonal dynamics of any single forest stand. Most of the previous relationships' successes were obtained by including a wide variety of vegetation types in deriving the original LAI values. Additionally. the LAI measurements were inherently unresponsive to seasonal changes because most *were* derived using regression relationships between leaf area per tree and a relatively stable tree dimension, such as diameter breast height (dbh). with both variables collected at various times throughout the growing season and often in different years (Gholz et al.. 1979). Gholz et al. (1991) were the first to generate a relationship between Normalized Difference Vegetation Index (NDVI) calculated from data recorded by the Landsat TM sensor and LAI of slash pine plots that were measured during the month of the satellite overpass. They reported that LAI increased from February to

September and decreased from September to March. Their study demonstrated the potential value of Landsat TM data for the estimation of seasonal changes in a single forest type. From this initial study Gholz et al. (1991) suggested that further studies involving spectrally-mixed models were needed to evaluate the magnitude of the relationship of LAI and NDVI of forest stands. Spanner et al. (1984) and Running et al. (1986) reported good linear relationships and high correlations between the NDVI and LAI in a northwestern U.S. coniferous forest. Gholz (1982) and Waring (1983) reported that canopy (LAI) had a strong functional relationship to stem wood biomass and net primary productivity.

Sader et al. (1989) reported that NDVI calculated from Landsat TM data were not significantly correlated with forest regeneration age classes in the mountain terrain of the Luquillo Experimental Forest. Puerto Rico. However, the NDVI calculated from low altitude aircraft scanner data was significantly correlated with forest age classes. Analysis of variance of the same data suggested that NDVI differences were not detectable for successional forests older than approximately 15-20 years. Also, biomass differences in young successional tropical forests were not detectable using NDVI. They concluded that the vegetation index did not appear to be a good predictor of stand structure variables, such as height and diameter of main stem, or total biomass in an uneven aged, mixed broadleaf forest. However, good correlations between the vegetation index and low biomass in even aged pine plantations were achieved for the warm temperature study site located in southern Mississippi. They further stated that TM • NDVI was sensitive to variation in the crown area and green biomass in pine stands and that a strong linear relationship was achieved between NDVI and total tree biomass. However, as the hardwood biomass component increased relative to pine biomass, the relationship between total stand biomass and NDVI decreased.

Peterson et al. (1987) reported a correlation coefficient of .95 between LAI and NIR/R band ratio for forests in the Pacific Northwest using TM data. Herwitz et al. (1990) investigated the possibility of using TM data to detect differences and changes in the LAI of thinned and closed canopy pine plantations on a local scale in central Massachusetts using the Band4/Band3 ratio index (RI). They found that a thinning treatment of 25% or more resulted in a significant decrease in the ratio index and that the relationship between RI and LAI of the unthinned plantation, which had LAI values ranging from 3.96 to 7.01. was not significantly different from the thinned plantation. They concluded that the TM sensor may be used best to detect moderate changes and differences in the LAI of closed pine plantations at local scales rather than for field observations including allometric equations.

Studies using data gathered by the Advanced Very High Resolution Radiometer (AVHRR) sensor on a regional and global scale have also yielded mixed results. Running and Nemani (1988) concluded that estimates of vegetation productivity using the global vegetation index (GVI) should only be done as annual integrations until unsubsampled local area coverage NDVI data could be tested against forest photosynthesis, transpiration and above ground net primary production, measured at shorter time intervals. Cihlar et al. (1991) analyzed the relationship between AVHRR generated NDVI and ecological variables. They found that individual vegetation/soil combinations exhibited different NDVI trajectories, most closely related to the trends in potential evapotranspiration. They reported a highly significant association between coincident NDVI and actual evapotranspiration for the previous 15-day period and high correlations between cumulative actual evapotranspiration over the growing season. They concluded that the relationship betwen NDVI and LAI depends on the type of ecosystem because of differences in canopy closure/density, under-story type and density, and the presence of standing water or rock outcrops within the scene.

Dijk et al. (1987) devised a method to reduce the effects of radiometric disturbances on remotely-sensed data without quantitative knowledge of the variable interactions that cause them. The method involved deriving composite weekly vegetation index values from the daily values for the area to be assessed followed by a smoothing of the weekly values over a selected period of time. Goward et al. (1991) reported that factors related to instrument precision and calibration, atmospheric attenuation and off-nadir viewing created deviations of the NDVI observations unrelated to vegetation dynamics. Deviations in excess of 50 percent between the satellite and equivalent ground observations were possible ii no effort was made to account for these effects. Additionally, off nadir viewing caused spatiotemporal variations in the measurements, and cloud occurence reduced temporal resolution below the AVHRR's daily repeat cycle. They suggested that these errors could be reduced to approximately 10 percent (0.1 NDVI) with a monthly time resolution if all of the observation attributes were addressed adequately and that much of the remaining error would reside in atmospheric variability, uncertainties in oh-nadir views and loss of sensor precision at large solar zenith angles.

Franklin (1986). using an airborne Thematic Mapper simulator, reported that the dominant spectral feature in his study was the amount of bright background soil revealed by the conifer canopy. Spanner et al. (1990) also reported that relationships between TM data and LAI were confounded by the conifer forests with incomplete canopy closure over an understory or ground surface condition that differed in brightness from the conifer overstory.

Eliminating the effects from exposed soil in radiometric studies of vegetative plot could have a significant effect on the spectral signatures of land cover, epecially forest stands. that one is able to differentiate. The ratio index has been used as a means to normalize the soil background signal (Shah-Demetriades et al.. 1990). Correlation coefficients between LAI and RI of .95 have been reported for close canopy forests in the Pacific Northwest (Peterson et al., 1987).

METHODOLOGY

The study site was located on the E.V. Smith Research Station. near Auburn University, Alabama (Figure 1). The soils were of the Marvyn series (fine-loamy, siliceous, thermic, Typic Hapludults) and are typical of sites in the upper Coastal Plain of Alabama. Eighty-eight rectangular plots measuring 5 m x 9 m with 1 m between plots containing different combinations and densities of loblolly pine seedlings, sweetgum seedlings and broomsedge grass seedlings were established.

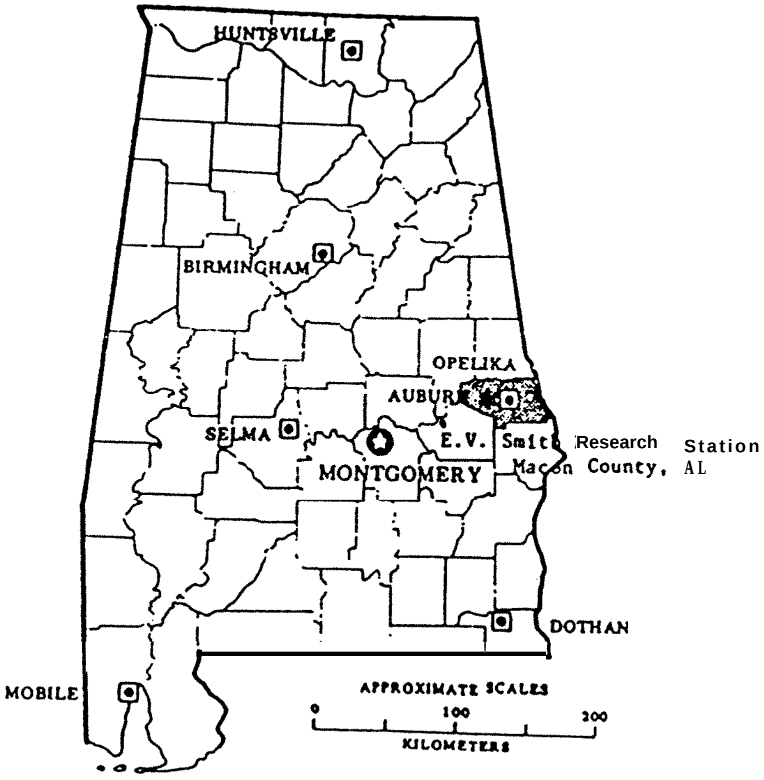

Figure 1. Location of the E.V. Smith State Agricultural Experiment Station, Macon County, Alobana.

The plots were selected from an addition series experiment in which a complete factorial combination of the loblolly pine and sweetgum seedlings each at 0, 1, 2. and 4 plants/m^2 and broomsedge at 0. 1, 4, and 16 plants/m^2 were established (Mitchell et al., 1990). The plots were replicated four times in a randomized complete block design. Some of the replications were not used in this study. Only plots with 1 pine/m^2 were examined because this was more representative of plantation conditions.

The sweetgum and broomsedge seedlings were planted one year prior to planting of the loblolly pine seedlings. The sweetgum seedlings were nursery raised and the broomsedge seedlings were wild plants obtained from two local fields. Following planting, the sweetgum and broomsedge seedlings were irrigated and given weed control for one entire growing season to ensure maximum survival and the development of a well established root system. During the following dormant season, the sweetgum and broomsedge seedlings were excised at the groundline. and the resulting sprouts were allowed to grow with the newly planted loblolly pine seedlings.

The loblolly pine seedlings were grown from half-sib seed produced from an improved upper Coastal Plain genotype. The seedlings were were 1 year old when transplanted in February, 1990. The plots were kept free of weeds by hand weeding and in some cases when necessary by herbicide treatments.

Spectral data from the plots were acquired from June 26 through July 5, 1990 with a Barnes Multiband Modular Radiometer (MMR), Model 12-1000, attached to a Polyoorder data recorder. Spectral reflectance of the vegetative plots was measured by attaching the radiometer to a manned truck-mounted telescopic boom. The data were collected between 1000 h Central Standard Time (CST) and 1400 h CST when the sun was almost overhead and clouds were not in the vicinity. Spectral measurements were acquired in eight bands: Band1=0.45 to 0.52 pm (blue), Band2=0.52 to 0.62 pm (graen). Band3=0.63 to 0.69 pm (red), Band4=0.76 to 0.90 pm and Band5=1.15 to 1.30 pm (near infrared). Band6=1.55 to 1.75 pm and Band7=2.03 to 2.35 pm (middle infrared), and Band8=10.40 to 12.50 pm (thermal infrared). The radiometer was elevated 12.2 m above the ground surface and vertical spectral readings were recorded within a S degree instantaneous field-of-view (IFOV) at a selected nadir position within each plot. This resulted in a circular plot area with a radius of 1.07 m. The spectral data were referenced to a barium sulfate calibration panel approximately every five minutes (Robinson and Biehl, 1979). Bidirectional reflectance factors (BRF) were determined according to the procedure described by Nicodemus et al. (1977). BRF is the ratio of the flux reflected by angles of irradiation and viewing to the flux reflected by the ideal completely reflecting, perfectly diffusing surface. identically irradiated and viewed.

The percentage of the IFOV covered by vegetation was independently estimated from photographic images on 35 mm color slides recorded concurrently with the radiometric data. The slides were projected onto a dot gridded screen and the ground area in the IFOV was located using a red flag at the nadir position. The grid was 80 x 100 cm and contained 1353 dots at 2.5 cm intervals. The equivalent screen area representing the ground field-of-view was calculated and demarcated using the Camera focal length lens and radius of the circular field of view. The ratio of dots falling on vegetation to the total number of dots in the IFOV was used as the estimated percent vegetative cover (VC). The amount of bare soil exposed to the radiometer was the difference between the estimated VC and 100 percent. Considerable bare soil characterized these plots due to the young age of the vegetation.

The vegetation indices and methodology used to compute them from the bidirectional reflectance factors were as follows. The ratio index (RI) was calculated as Band4/Band3. The normalized difference vegetation index (NDVI) was calculated as (Band4 • Band3)/(Band3 + Band4). A corrected normalized difference vegetation index (CNDVI) was calculated using the following formula:

$$CNDVI = NDVI_{plot} \bullet (100 \bullet VC)^{*} NDVI_{soil} \tag{1}$$

where: $NDVI_{plot}$ = Normalized difference vegetation index of the vegetation plots: VC = Vegetative cover: $NDVI_{soil}$ = Normalized difference vegetation index of the soil plots.

Individual plant measurements were also made at the time of the spectral measurements for use in altometric equations to obtain estimates of above-ground biomass (RIO) and leaf area (LA). The loblolly pine measurements included plant height from ground level to the tip of the growing point (cm). the stem groundline diameter, maximum crown diameter and right-angle crown diameter, both from needle tip to needle tip (cm). To estimate all-sided LA and BIO the developed altometric equations for pine used the square of the groundline diameter and height.

The sweetgum variables measured were height (cm) and the two crown dimensions to leaf tips (cm) measured at right angles. which were used for computing LA (both-sided) and BIO. Broomsedge measurements were height (cm) to the tallest leaf and two maximum groundline diameters of each clump (mm) measured at right angles to each other. These measurements were used in computing LA and BIO using linear regression analyses. Allometric equations were calculated through destructive sampling of selected plant samples across all densities. Linear regression analyses were used with log transformations for both regression and LA and BIO.

The transformation of Baskerville (1972) was used to adjust the estimates from the equation since the logarithmic transformation of the data and fitting the model introduced a bias. These plant variables were used in regression analyses against the remotely-sensed variables of the plots for each phase of the study (SAS Institute. 1989).

RESULTS AND DISCUSSION

A summary of the mean, minimum and maximum value of LA, BIO and VC for the regeneration plots is given in Table 1. The results are quite variable which reflect the sparse vegetative cover characteristics of some of the plots, but provided the variation needed for regression analyses. Surprisingly, sweetgum had the lowest mean and maximum values recorded for LA compared to the other plots. The sweetgum plots also generated low BIO; however, the lowest mean and maximum values were generated from the loblolly/broomsedge mixed plots. Vegetative cover, which was determined independently from 35 mm slides, mean and minimum values generated from the sweetgum plots were considerably higher than the loblolly and broomsedge plots. However. caution must be exhibited when interpreting these data because the method used was subjected to bias induced by crown shadows which are similar in appearence to dead or senscent vegetation. Most of the broomsedge at the time of this study was determined to be in the senescent vegetative stage. A graph of the mean spectral values for the single and mixed forest regeneration plots is given in Figure 2. According to Jensen (1986), healthy green vegetation generally reflects 40 to 50% of the incident near-infrared energy (0.7 to 1.1 μm, Bands 4 and 5) with the chlorophyll in the plants absorbing 80 to 90% of the incident energy in the visible (0.4-0.7 μm, Bands 1, 2. and 3) region of the spectrum. Dead or senescent vegetation reflects a greater amount of energy in the visible spectrum and less in the near-infrared portion of the spectrum than healthy green vegetation. Dry soil generally has a higher response than green vegetation and lower response than dead vegetation in the visible region and a lower response in the near-infrared region than green or senescent vegetation.

Table 1. Means of leaf area (LA), above-ground biomass (BIO) and percent vegetative cover (VC) of single and mixed forest regeneration plots.

	LA(cm3)			BIO (cm3)			VC(%)		
Species[1]	Mean	Min[2]	Max[3]	Mean	Min[2]	Max3	Mean	Min[2]	Max[3]
LL	18.0	4.5	39.1	1.9	0.4	4.0	18.7	3.8	59.4
SG	9.6	3.4	18.5	1.3	0.5	2.6	56.0	14.2	88.5
BS	26.4	0.0	48.1	1.3	0.0	2.3	42.3	3.3	94.8
LL/SG	13.9	7.8	21.9	1.7	0.8	2.8	58.2	29.2	91.0
LL/BS	22.4	5.9	34.9	0.5	0.2	1.1	47.5	5.2	96.2
LL/SG/BS	26.5	6.1	39.3	1.9	0.7	2.6	81.7	30.8	99.0

[1] LL = Loblolly pine; SG = Sweetgum; BR = Broomsedge
[2] Min = Minimun value recorded
Wax = Maximum value recorded

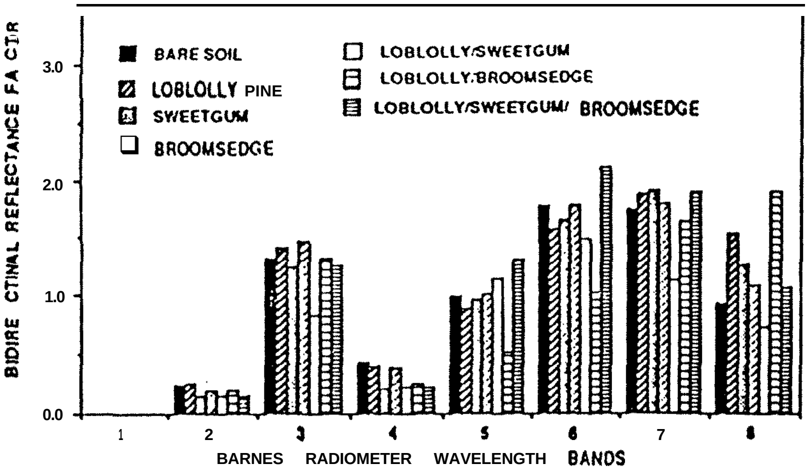

Figure 2. Mean bidirectional reflectance factors of single and mixed forest regeneration plots.

The data in Figure 2 show that there is very little separation in the visible spectral characteristics, Bands 2 and 3. of the single and mixed plant species. The near-infrared, middle infrared and thermal infrared spectral characteristics, Bands 4 through 8, appear to have some degree of separability among the vegetative and bare plots. However, the results of an analysis of variance and mean separation of the data revealed that there were no significant differences among the spectral characteristics of these forest regeneration plots. Data recorded by Band 1 was found to be faulty and was discarded from use in the analyses. According to Jensen (1986). most vegetation indices are based on the fact that there are significant differences in the shape of healthy green vegetation, dry or senescent vegetation and dry soil. If these curves are situated on top of one another, there is not much useful information that can be acquired.

The results of the correlation analyses among the spectrally-derived VIs and LA and BIO (Table 2) support the conclusions given by Jensen (1986) and the data presented in Figure 2. Poor correlations were observed among the VIs and LA and BIO of the single loblolly pine and broomsedge plots. Additionally, the relationships between VIs and LA and BIO of the mixed plots were also poor.

The best correlations among the VIs (NDVI and RI) and LA and BIO were observed for the single sweetgum plots, which produced correlation coefficients that exceeded .65 for each variable. These plots also contained the highest percentage of vegetative cover, i.e. less of the surface soil was in view of the radiometer. The low correlations observed were attributed to the close similarity in the spectral characteristics of the vegetation and the exposed soil within the plots.

Table 2. Correlation coefficients among spectrally-derived vegetation indices and leaf area (LA) and above-ground biomass (BIO) of loblolly pine, sweetgum and broomsedge plants.

		Spectral Indii		
species	Variables	NDVI	RI	CNOVI
Loblolly pine	LA	0.10	0.10	0.83”’
	BIO	0.10	0.09	0.83”’
Sweetgum	LA	-0.67’	-0.65’	0.92”’
	BIO	-0.68’	-0.66’	0.93”’
Broomsedge	LA	-0.14	0.11	0.12
	BIO	-0.16	-0.13	0.13
Loblollyl Sweetgum	LA	-0.40	-0.38	0.31
	BIO	-0.40	-0.37	0.42
Loblollyl Broomsedge	LA	-0.38	-0.37	0.80”
	BIO	-0.20	-0.19	0.68’
Loblollyl Sweetgum/ Broomsedge	LA	0.04	0.02	0.14
	BIO	-0.12	-0.13	0.14

[1] NDVI=Normalized Difference Vegetation Index: RI = Ratio Index; CNDVI = Corrected Normalized Difference Vegetation Index;

***,**,* Denotes significance al the .001, .01 and .05 level of probability. respectively

The effect of exposed soil on the NDVI was eliminated by multiplying the NDVI of the nearest bare soil plot by the percent of bare soil exposed to the radiometer and subtracting the NDVI of the vegetative plot by the results. The results revealed an increase in the amount of variation the relationship between the vegetation parameters (LA and BIO) and the corrected normalized vegetation index (CNDVI) could explain compared to the uncorrected NDVI. The most substantial increase was observed for the single loblolly pine plots. The relationship between LA and NDVI accounted for 10 percent of the variability. However, when NDVI was corrected for the percentage of exposed surface soil, the relationship between LA and CNOVI accounted for 83 percent of the variability, an increase of 73 percent. The relationship between BIO and CNOVI accounted for 83 percent of the variability which is an increase of 75 percent over the relationship between BIO and NOVI. These results confirm the effect which exposed surface soil has on vegetation indices generated from remotely-sensed data and their ability to predict vegetalion parameters such as LA and BIO. The exposed soil serves as a sink for electromagnetic radiation. and depending upon the surface soil moisture and organic matter content. the amount of radiation reflected is significantly reduced. Potential problems also exist with crown shading of younger or shorter plants by plants with larger crowns and shadows cast by the plants depending on the time of day the remotely-sensed data is collected.

Table 3 contains correlation coefficients between the organic matter content of the forest regeneration plots and the spectrally-derived VIs. LA and BIO. Most of the relationships are not significant; however, several account for over 25 percent of the variability. Vegetation indices based on spectral data acquired from radiometric sensors are severely affected by exposed soil as demonstrated in this study and other studies which have used satellite data to generate spectral indices (Spanner et al., 1990; Franklin, 1986). Eliminating for the soil effect will increase the level of accuracy of these vegetation indices in predicting LA and BIO of forest plots.

Table 3. Correlation coefficients between organic matter content, spectrally-derived vegetation indices, leaf area (LA) and above-ground biomass (BIO) of forest regeneration plots.

	Species[2]					
Variable[1]	LL	SG	BS	LL/SG	LL/BS	LL/SG/BS
LA	0.25	0.04	0.23	0.41	0.41	0.14
BIO	0.30	0.06	0.23	0.40	0.55	0.43*
NDVI	-0.14	-0.24	-0.53	-0.73**	0.16	0.14
RI	-0.13	-0.22	-0.52	-0.56*	0.18	0.14
CNDVI	0.42	0.20	0.17	-0.37	0.16	0.14

[1] NDVI=Normalized Difference Vegetation Index; RI=Ratio index; CNDVI=Corrected Normalized Difference Vegetation Index

[2] LL=Loblolly pine: SG=Sweetgum; BS=Broomsedge

**,* Denotes significance at the .01 and .05 level of probability. respectively.

Predicting Vegetation Parameters from Vegetation indices (VIs)

The best relationship for predicting LA among the spectrally-derived VIs was generated using the CNDVI (Table 4). The equations and amount of variability that are explained differ according to the vegetation. The loblolly pine seedlings' LA could be predicted at an accuracy of 68 percent and the sweetgum seedlings at an accuracy of 85 percent. None of the VIs predicted LA of the broomsedge plots very well as evident by the very low R^2 values. The best equation for predicting LA in the mixed plots was generated using the CNDVI of the loblolly/broomsedge mixed plots. which accounted for 64 percent of the variability (Table 5).

The best relationship for predicting BIO using the spectrally-derived VIs was also generated using the CNDVI (Table 6). The results and trends were similar to those observed for predicting LA. The best prediction equation was generated from the sweetgum seedling plots which accounted for 86 percent of the variability. The BIO of the loblolly pine seedlings could be predicted at an accuracy of 69 percent. The best equation for predicting the BIO in the mixed vegetation plots was achieved using the CNDVI from the loblolly/broomsedge plots which accounted for 46 percent of the variability (Table 7).

Table 4. Regression equations for estimating leaf area (LA) of forest species from spectrally-derived vegetation indices.

Species	n	b_0	b_1	VIs[1]	R^2
Loblolly	16	26.51	+15.09	NDVI	0.010
	16	1.40	+1.68	RI	0.009
	16	56.22	+43.01	CNDVI	0.685"
Sweetgum	11	-19.77	-40.62	RI	0.452'
	11	18.82	-56.51	CNDVI	0.426'
	11	17.29	+14.79		0.854"
Broomsedge	12	12.56	-22.59	RI	0.020
	12	31.66	-21.70	CNDVI	0.011
	12	29.58	+5.26		0.013

[1]NDVI=Normalized Difference Vegetation Index; RI=Ratio Index; CNDVI = Corrected Normalized Difference Vegetation Index.
**,* Denotes significance at the .01 and .05 level of probability.

Table 5. Regression equations for estimating leaf area index (LA) of mixed forest plots from spectrally-derived vegetation indices.

Species	n	b_0	b_1	VIs[1]	R^2
Loblolly/	12	10.38	-6.10	NDVI	0.162
Sweetgum	12	15.64	-4.68	RI	0.145
	12	16.18	+5.10	CNDVI	0.099
Loblolly/	12	-16.15	-56.92	NDVI	0.144
Broomsedge	12	37.86	-79.38	RI	0.137
	12	35.58	+21.55	CNDVI	0.642"
Loblolly/	24	31.30	+6.74	NDVI	0.002
Sweetgum/	24	25.60	+5.28	RI	0.001
Broomsedge	24	27.76	+5.59	CNDVI	0.081

[1]NDVI=Normalized Difference Vegetation Index; RI=Ratio Index: CNDVI = Corrected Normalized Difference Vegetation Index.
**,* Denotes significance at the .01 and .05 level of probability.

Table 6. Regression equations for estimating above-ground biomass (BIO) of forest species from spectrally-derived vegetation indices.

Species	n	b_0	b_1	VIs	R^2
Loblolly	16	2.60	+1.29	NDVI	0.007
	16	6.24	+44.04	RI	0.029
	16	5.80	+4.39	CNDVI	0.690”
Sweetgum	11	-2.94	-5.93	NDVI	0.465’
	11	2.69	-8.26	RI	0.440’
	11	2.45	+2.13	CNDVI	0.857”
Broomsedge	12	0.49	-1.29	NDVI	0.027
	12	1.60	-1.30	RI	0.017
	12	1.45	+0.28	CNDVI	0.016

[1] NDVI=Normalized Difference Vegetation Index; RI=Ratio Index; CNDVI = Corrected Normalized Difference Vegetation Index.

- ‘.’ Denotes significance at the .01 and .05 level of probability

Table 7. Regression equations for estimating above-ground biomass (BIO) of mixed forest species from spectrally-derived vegetation indices.

Species	n	b_0	b_1	VIs[1]	R^2
Loblolly/ Sweetgum	12	1.22	-0.83	NDVI	0.159
	12	1.93	-0.63	RI	0.140
	12	2.11	+0.93	CNDVI	0.175
Loblolly/ Broomsedge	12	0.28	-0.54	NDVI	0.040
	12	1.73	-2.08	RI	0.035
	12	1.89	+0.93	CNDVI	0.455’
Loblolly/ Sweetgum/ Broomsedge	24	1.14	-1.07	NDVI	0.013
	24	2.20	-1.77	RI	0.018
	24	26.95	-0.05	CNDVI	0.002

[1] NDVI=Normalized Difference Vegetation index; RI=Ratio Index; CNDVI= Corrected Normalized Difference Vegetation Index.

**,* Denotes significance at the .01 and .05 level of probability

The relationships between BIO and the other VIs were quite poor and accounted for considerably less of the variability in the data than the CNDVI. Sader et al. (1989) attributed the decreased relationship between BIO and NDVI of their mixed plots to the increased component of the hardwood biomass relative to the pine biomass. In this study the sweetgum seedlings also appeared to be the dominant species attributing to the spectral response of the regeneration plots. The 35 mm slides revealed that the sweetgum seedlings produced a considerable amount of crown shading of the loblolly and broomsedge seedlings which could have had an effect on the calculated LA and BIO of the mixed plots. Correlation coefficients generated using the VC data derived from the procedure using the 35 mm slides revealed that highly significant relationships exist among VC, LA and BIO of the loblolly and sweetgum plots. These relationships generated correlation coefficients of .89 and .88 for loblolly VC versus LA and BIO, respectively and .95 and .96 for sweetgum VC versus LA and BIO. respectively. Prediction equations were also generated from these relationships which accounted for 80 and 78 percent of the variability for loblolly VC versus LA and BIO, respectively and 91 percent of the variability for sweetgum VC versus LA and BIO.

CONCLUSIONS

The results of this study revealed that the corrected normalized difference vegetation index (CNDVI) which is adjusted for the exposed bare soil shows promise for predicting leaf area and above-ground biomass in single or mixed forest regeneration plots. The relationships and amount of variability explained between the spectral indices and LA and BIO decreased in the plots that contained two or more species. Correcting for the interference of bare soil was necessary to give reasonably accurate predictability of LA and BIG. The best relationship between the CNDVI and LA and BIO was achieved with the single sweetgum plots accounting for 92 and 93 percent of the variability in the data, respectively. The relationship between the CNDVI and LA and BIO of the loblolly pine plots also generated significant correlations of .83. The sweetgum seedlings appeared to be the dominant species in accounting for the variability in the data of the mixed plots. This could be attributed to the larger crowns of the sweetgum seedlings shading the other species. The 35 mm slides were used to obtain an estimate of the percentage of bare soil exposed to the radiometer and its effect on spectrally-derived VIs. Utilizing the percentage of bare soil exposed to the radiometer in the calculation of NDVI show promise in the use of this corrected VI in predicting LA and BIO. These prediction equations have not been validated with other data; however. their R^2 values were significantly higher than the uncorrected NDVI R^2 values for all of the plots used in this study. Other means of accounting for the bare soil effect need to be develop as well as further testing of this proposed technique.

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