SELECTION OF OPTIMAL HYPERSPECTRAL VEGETATION INDICES FOR ESTIMATING CHLOROPHYLL CONTENT OF SOME PLANT SPECIES

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Remote sensing enables for cost-effective, timely efficient and multi-temporal monitoring of natural vegetation. Spectral reflectance pattern either in forms of row reflectance values or form of spectral vegetation indices (SVIs) could be used as estimators of plant biophysical and biochemical parameters through statistical models. The main objective of the current study is to correlate plant chlorophyll concentration with different (SVIs) and to identify the most sufficient index to discriminate among the twenty common natural vegetation species in Sinai Peninsula. Calculated values of five hyperspectral vegetation indices (normalized difference vegetation index (NDVI); Chlorophyll Index; Chlorophyll a,b; Simple ratio index (SRI); Modified chlorophyll absorption ratio index (MCARI) for the twenty observed vegetation species were used as spectral factors in the modeling process. The result showed that the relatively high chlorophyll content was found in broad leaves plants when needle-leaved plant species showed relatively low ones. Laboratory chlorophyll estimation indicated that Asclepias sinaica had the highest chlorophyll content (79 mg cm^{-2}) when the same plant specious showed the highest chlorophyll index value. It was found that plants of family *Zygophyllaceae* have low chlorophyll content. Among observed SVIs, NDVI was the most correlated index with chlorophyll. At the same time, it was the optimal index to differentiate the different species.

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INTRODUCTION

Evolution in hyperspectral remote sensing can provide more exact information on structural and biochemical properties of plant species.[1] Most of the work on hyperspectral remote sensing of biophysical and biochemical prosperities has been achieved through the evolution of new hyperspectral indices.[2,3,4] Spectral indices are mathematical processing of spectral reflectance to promote vegetation signal.[5,6] Vegetation indices might supply new capabilities for discriminate plant species or communities that differ in vegetation structure.[7] NDVI (normalized difference vegetation index) calculation is based on the difference in canopy reflectance at red and near-infrared wavelengths.[8,9] NDVI has been used to differentiate plant species consisting of structurally featured formations, e.g., shrubland and forest (Table 1)[10,11] or phenological featured formations.[12] New hyperspectral indices that supply correlation with the biochemical properties of canopies have been developed. Several studies show that narrow band vegetation indices involving visible reflectance near 550 and 700 nm can estimate leaf chlorophyll content such as chlorophyll a and b[13] and carotenoids.[14,15] These pigments play important roles within the process of photosynthesis, and their concentrations can depend on some factors such as phenology, the degree of canopy development and type of environmental stress.[16] Spectral vegetation indices constitute a simple and restful approach to evolve information from remotely sensed data, due to their facility of use, which facilitates the processing and analysis of huge amounts of data obtained by satellite platforms.[17,18] Increasing efforts have focused on comprehension the relationships between vegetation optical properties and photosynthetic pigments concentrations within green leave tissues such as chlorophylls and carotenoids.[19,20,21]

Table 1. Uses of vegetation indices

Vegetation indices	Uses
NDVI (normalized difference vegetation index)	Used to estimate vegetation biomass, vegetation productivity, and biochemical properties.[21] Have the best correlation with leaf chlorophyll concentrations.[22]
Chlorophyll Index	Chlorophyll concentration in the leaf.
Chlorophyll a and b	Chlorophyll a and b concentration in leaf.
SRI (simple ratio index)	Used to estimate biochemical properties at the species, canopy and landscape level, reasonably predict canopy level chlorophyll content.[21]
MCARI (modified chlorophyll absorption ratio index)	Responsive to chlorophyll variation in the first place.[23]

Our objective in this study was to assess spectral indices for prediction of leaf chlorophyll content that is relatively insensitive to plant species and leaf structure variation.

MATERIAL AND METHODS

Flowering shoots of 20 plant species of wild Egyptian plants belonging to 19 genera were collected from natural habitats in Sinai Penninsula. A SPAD-502 Leaf Chlorophyll Meter (Minolta Inc.) was used to estimate the leaf chlorophyll content in each site. The chlorophyll meter (SPAD) provides a simple, quick, method for asses leaf chlorophyll content.[24] SPAD values express relative amounts of chlorophyll in leaves by measuring transmittance in the red (650 nm) and NIR (920 nm) wavelength regions. A total of 20 leaves representing each dominant species were randomly selected in each site. Chlorophyll concentration was measured 3 times at different leaf location and their SPAD readings were recorded. From the 20 individual SPAD measurements, the average was calculated according to Ref.[25] (Table 4). Field spectroradiometer was used to measure the reflection of the twenty plant species under investigation. Measurements were acquired in Visible, Near Infrared and Short Wave Infrared from 350 nm to 2500 nm with 1 nm interval output data. However, the ASD device Software interpolates the final output data with interval 1nm for all spectrum range 350 - 2500 nm (table 2). The intervals which ASD spectroradiometer is capturing the reflectance is 1.4 nm at visible and near-infrared ranges, while it is 2 nm at the shortwave infrared spectral range. The spectrum characteristics of the device are shown in Table 3. Spectral response for different targets was acquired according to ASD Spectroradiometer measurements protocol, where the reference spectral measured as radiance from a Spectralon® panel to ensure standardized environmental conditions for the reflectance measurement. Moreover, the flexibility of fiber-optic cable provides instrument adaptation for a wide range of applications. The measurements were performed by holding the pistol grip by hand. The Bare fore optic 25 degrees used for outdoor measurements resulting circular field of view with 3 cm diameter as measurements were taken at 3 cm height in nadir position (90 degrees) over the measured plants.

Table 2. The ASD field Spec 3 specifications.

Spectral range	350 - 2500 nm
Spectral resolution	3:700 nm 8.5:1400 nm 6.5:2100 nm
Sampling interval	1.4:350 - 1050 nm 2:1000 - 2500 nm

Considerations of spectroscopy measurements, ASD, field spectrometer

The sources of information pertinent to the issues affecting spectral measurements are fragmented. Further, there are no such documents or manuals that synthesize all the factors influencing spectral measurements and the methods used to minimize and account for extraneous factors in spectral measurement. Issues to be considered when designing a spectral library database have been summarized.[26] The factors that affect standardized measurements can be summarized to include: environmental conditions.

Vegetation indices and chlorophyll content

The values of VIs that calculated from spectroscopy measurements for each plant in the field, it is based on the contrast between maximum absorption of the red spectrum by chlorophyll and pigments followed by maximum reflectance in near infrared spectrum by leaf cellular structure as presented in Table 3. The correlation between five different (VIs) and chlorophyll content was observed and expressed through mathematical correlations as explained in Table 3.

Table 3. Summary of vegetation indices, algorithms and sources for vegetation indices.where R_x is the reflectance at the given wavelength (nm)

Index description	Formation	Ref.
NDVI (Normalized difference vegetation index)	$(R_{800}\ R_{680})/(R_{800}+R_{680})$	7
SR (Simple ratio)	R_{750}/R_{710}	27
Cab (Leaf Cab Concentration)	$(R_{750}-R_{705})/(R_{750}+R_{705})$	15
CL (Chlorophyll Index)	$[R_{750}/(R_{700}+R_{710})]-1$	15
MCARI (Modified chlorophyll absorption ratio index)	$(R_{700}-R_{670})-0.2(R_{700}-R_{550})-R_{700}/R_{670}$	23

RESULTS AND DISCUSSION

Extraction of some biophysical parameters from remote sensing data

Asclepias sinaica showed the highest chlorophyll content (79 mg cm^{-2}) followed by *Phlomis aurea* (73 mg cm^{-2}) while the lowest chlorophyll content was found in *Fagonia glutinosa* (4mg cm^{-2}). The correlation between chlorophyll content and remotely sensed data was presented in forms of vegetation indices-chlorophyll correlations as shown in the Figure 1a-1e, Table 5 and 6 and equations.

Results for the regression analysis showed that all of the vegetation indices in the present study positively correlated with the chlorophyll content as follows.

A strong correlation (R^2= 0.94) has been found between Normalized Difference Vegetation Index (NDVI) and chlorophyll Content as presented in (Figs. a) and the subsequent equation:

$$Y= 338.0x^2- -261.72x-51.613$$

A strong correlation (R^2= 0.92) was also found between Chlorophyll index and chlorophyll content as shown in (Figs. b) and the subsequent equation:

$$Y= 72.103x^2- 167.05x-11.133$$

A good correlation (R^2= 0.87) was observed between leaf (Cab) concentration and chlorophyll content as shown in (Figs. c) and the subsequent equation:

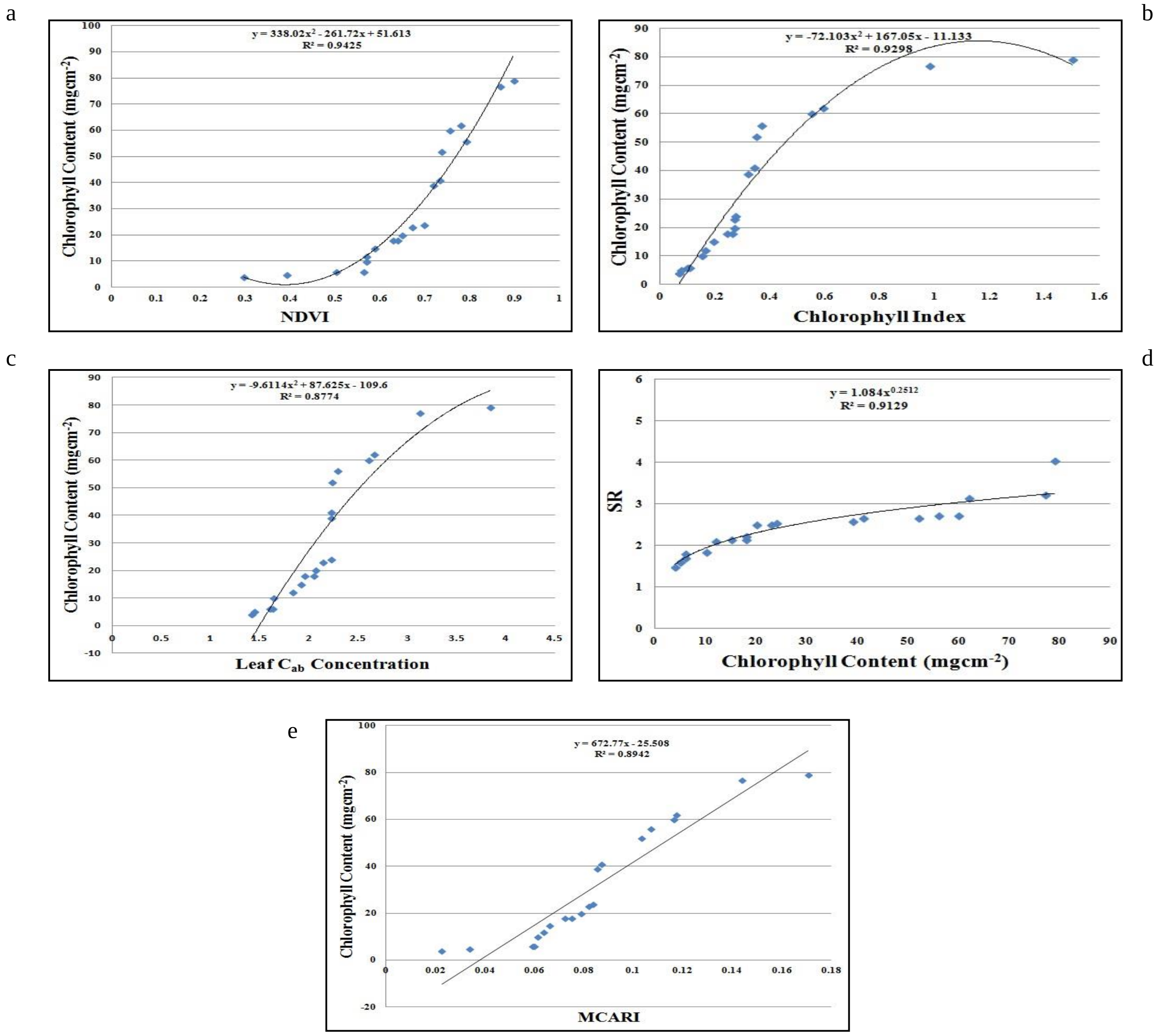

Figure 1a-e. The correlation between chlorophyll content and difference vegetation indices **a.** The relation between (NDVI) and chlorophyll content to differentiate between studied taxa, **b:** Relation between chlorophyll index and chlorophyll content, **c.** The relation between leaf C_{ab} concentration and chlorophyll content, **d.** Relation between simple ratio (SR) and chlorophyll content and **e**. Relation between (MCARI) and chlorophyll content

$$Y= 9.6114x2-67.625x-109.6$$

A strong correlation (R^2= 0.91) was also found between the normalized simple ratio (SR) and chlorophyll content as shown in (Fig. 1d) and the subsequent equation:

$$Y= 1.084x0.2512$$

A good correlation (R^2= 0.89) was found between the modified chlorophyll absorption ratio index (MCARI) and chlorophyll content as shown in (Fig. 1e) and the subsequent equation.

$$Y= 672.77x-25.508$$

Table 4. Chlorophyll content of studied taxa.

Plant	**Chlorophyll content (mg cm^2)**
Achillea fragrantissima	10
Aerva tomentosa	18
Alkanna orientalis	52
Asclepias sinaica	79
Astragalus sieberi	15
Ballota kaiseri	39
Echinops spinosus	73
Fagonia glutinosa	4
Hyoscyamus muticus	41
Matthiola arabica	23
Matthiola longipetala	24
Origanum syriacum	74

Peganum harmala	6
Phlomis aurea	77
Pyrethrum santolinoides	12
Stachys aegyptiaca	18
Teucrium polium	20
Verbascum sinaiticum	56
Zilla spinosa	6
Zygophyllum simplex	5

Table 5. Correlation coefficients between the original indices and chlorophyll content of studied taxa.

Plant	NDVI	MCARI
Fagonia glutinosa	6.973	0.0749
Peganum harmala	8.962	0.0853
Zygophyllum simplex	7.521	0.1440
Matthiola arabica	0.715	0.0614
Matthiola longipetala	5.852	0.0662
Zilla spinosa	0.499	0.0787
Achillea fragrantissima	3.891	0.0226
Echinops spinosus	5.671	0.0835
Origanum syriacum	7.772	0.1707
Pyrethrum santolinoides	7.301	0.0819
Phlomis aurea	0.647	0.0593
Stachys aegyptiaca	0.294	0.0336
Teucrium polium	6.692	0.0722
Verbascum sinaiticum	6.251	0.0871
Aerva tomentosa	0.735	0.0600
Alkanna orientalis	6.361	0.1032
Asclepias sinaica	0.561	0.1173
Astragalus sieberi	5.673	0.0637
Ballota kaiseri	7.401	0.1071
Hyoscyamus muticus	8.654	0.1165

Table 6. Spectral indices related to biochemical and biophysical vegetation parameters: NDVI, normalized difference vegetation index; MCARI and the modified chlorophyll absorption ratio index

Vegetation indices	R^2
NDVI	0.94
Chlorophyll index	0.92
Cab	0.87
SR	0.91
MCARI	0.89

Regarding chlorophyll content analysis, showed that generally, the high chlorophyll was found in these plant species with broad leaves when needle-leaved plant species showed low chlorophyll content also noticed that plant of family Zygophyllaceae has low chlorophyll content. Results for the regression analysis showed that all of the observed vegetation indices positively correlated with the chlorophyll content. It was found that Strong correlation between, NDVI and chlorophyll content (R^2= 0.94) and also a good correlation (R^2= 0.91) between simple ratio and chlorophyll index. This agreed with Ref.[14] who reported the strong correlation between vegetation indices and chlorophyll content. High values of these indices and their strong correlation with chlorophyll content indicated the high capability of the VIs as indicators for plant status and physiological condition. The strong correlation (R^2= 0.88) between chlorophyll content and the calculated leaf Cab concentration also showed the method in which remote sensing tools could be used to estimate plant biophysical parameters instead of the other time consuming and costly traditional methods. This agreed with Refs.[28,29]

Table 7. Spectral indices related to biochemical and biophysical vegetation parameters: SR, simple ratio; Cab, Chlorophyll a, b.

Plant	Chloro-phyll Index	Leaf Cab Concen-t-ration	SR
Fagonia glutinosa	0.319	2.223	0.319
Peganum harmala	0.368	3.836	2.576
Zygophyllum simplex	0.241	2.046	4.033
Matthiola arabica	0.550	2.602	2.498
Matthiola longipetala	0.104	1.947	2.510
Zilla spinosa	0.0986	1.621	3.2296
Achillea fragrantissima	0.151	1.595	1.480
Echinops spinosus	0.0736	1.635	2.539
Origanum syriacum	0.162	2.058	0.162
Pyrethrum santolinoides	0.346	2.284	2.667
Phlomis aurea	0.339	2.233	2.655
Stachys aegyptiaca	0.260	1.416	2.713
Teucrium polium	0.267	2.132	2.721
Verbascum sinaiticum	0.2732	2.221	3.149
Aerva tomentosa	0.590	2.654	1.599
Alkanna orientalis	1.498	1.829	1.704
Asclepias sinaica	0.191	1.439	1.804
Astragalus sieberi	0.069	1.909	1.849
Ballota kaiseri	0.267	2.215	2.104
Hyoscyamus muticus	0.979	3.120	2.147

CONCLUSION

The result showed that Normalized Difference Vegetation Index (NDVI) was the most correlated index to chlorophyll content. Also, it was the optimal vegetation index to differentiate among the different species. It was found that plants of family Zygophyllaceae have low chlorophyll content as also indicated by chlorophyll spectral index. The study showed high compatibility between spectral index and biochemical parameters of the natural vegetation. The study succeeded in generating statistical correlation to retrieve chlorophyll from spectral reflectance data with high accuracy.

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