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OPTICAL PARAMETERS OF LEAVES OF SEVEN WEED SPECIES

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Abstract

Absorption coefficient (k), infinite reflectance (R^{∞}), and scattering coefficient (s) were tabulated for five wavelengths and analyzed for statistical differences for seven weed species. The wavelengths were: 0.55-μm, 0.65-μm, 0.85-μm, 1.65-μm, and 2.20-μm. The R^{∞} of common lambsquarters (Chenopodium album L.), Johnsongrass (Sorghum halepense (L.) Pers.), and annual sowthistle (Sonchus oleraceus L.) leaves at the 0.85-μm wavelength were significantly ($p = 0.05$) higher than for sunflower (Helianthus annuus L.), ragweed parthenium (Parthenium hysterophorus L.), or London rocket (Sisymbrium irio L.). Annual sowthistle had the largest k value, and Palmer amaranth (Amaranthus palmeri S. Wats.) had the smallest k value at the 0.65-μm chlorophyll absorption wavelength. In general, johnsongrass, ragweed parthenium, or London rocket had the largest s values among the five wavelengths, whereas annual sowthistle and Palmer amaranth were usually lowest.

INTRODUCTION

The optical parameters k, R^{∞}, and s have been tabulated for seven wavelengths, and analyzed for statistical differences for 30 plant species (6). The wavelengths were: 0.55-μm (green peak), 0.65-μm (chlorophyll absorption band), 0.85-μm (infrared reflectance plateau), 1.45-μm (water absorption band), 1.65-μm (reflectance peak following water absorption band at 1.45- m), 1.95-μm (water absorption band), and 2.2-μm (reflectance peak following water absorption band at 1.95-μm).

Our objective was to present significant differences among the three optical parameters for seven weed species at the 0.55-μm, 0.65-μm, 0.85-μm, 1.65-μm, and 2.2-μm wavelengths. The optical parameters can be used to predict the response of a weed leaf to insolation. The rate of photosynthesis will be affected by changes in the amount of insolation in the PAR (0.4 to 0.7-μm) that is absorbed, reflected, or scattered by a single weed leaf (3, 5). Optical parameters could be especially useful for determining the amount of insolation absorbed by a weed leaf. Insolation absorbed by a weed leaf is energy lost to the photosynthetic activity of useful crops, and will have a corresponding effect on yield. Thus, data presented in this paper should be of interest to investigators developing various crop yield models (4).

These data should also be of interest to the crop discrimination problem in remote sensing. The data presented could be used for investigation work using Suit's (14) plant canopy reflectance models and Smith and Oliver's (12) stochastic plant reflection model. These models could be used to infer crop and weed reflectance from LANDSAT altitudes using atmospheric radiative transfer correction procedures as presented by Richardson et al. (11). These crop reflectance modeling studies would have application to remote sensing in weed science for the detection of weeds in various crops and for studying the associated crop yield reductions (9).

MATERIALS AND METHODS

Ten fully expanded and healthy appearing leaves were collected from each of the seven field-grown weed species: ragweed parthenium, lambsquarters, sunflower, annual sowthistle, Palmer amaranth, johnsongrass, and London rocket. The adaxial leaf surfaces of the weed species were essentially glabrous, except that sunflower leaves were sparsely pubescent. Johnsongrass leaf venation was parallel, whereas venation was netted in the other species. Leaves were positioned on the spectrophotometer so that veins or hairs did not interfere with the impinging light beam. Immediately after excision, leaves were wrapped in Saran or Glad-Wrap to minimize moisture loss. Leaves were wiped with a slightly dampened cloth preceding spectrophotometric measurements to remove surface contaminants.

The R_∞, k, and s coefficients were calculated by the equations of Allen and Richardson (1):

$$R_\infty = 1/a, \quad \text{(I)}$$

$$k = ((a - 1)/(a + 1))\log b, \quad \text{(II)}$$

$$s = ((2a/(a^2 - 1)))\log b, \quad \text{(III)}$$

$$a = (1 + r^2 - t^2 + \ )/2r, \text{ and} \quad \text{(IV)}$$

$$b = (1 - r^2 + t^2 + \ )/2t, \text{ where} \quad \text{(V)}$$

a = optical constant, b = optical constant, r = reflectance, and t = transmittance. The quantity is defined by the relation

$$^2 = (1 + r + t)(1 + r - t)(1 - r + t)(1 - r - t) \quad \text{(VI)}$$

The quantities a and b (equations IV and V) are constants at a given wavelength. Because r and t vary with wavelength, the quantities a and b are also functions of wavelength. Light passing through a leaf is modeled as being absorbed and scattered in direct proportion to a differential distance, dn, traversed through the leaf and in direct proportion to the amplitude of the light at that point in the leaf. The quantity n is the cumulative leaf area index. Absorbed radiation disappears from the model. For the case of a single leaf (n = 1) Allen and Richardson's (1) equations reduce to the form shown above. For the case of n >1, two or more leaves are stacked, and the formulation becomes more complex (1). Scattered radiation is merely changed in direction. Because the model is one-dimensional, the scattering must be either forward or backward. The forward-scattered component is indistinguishable from the incident light, but the backward-scattered component adjoins the light moving in the opposite direction. The absorption coefficient k (equation II) and the scattering coefficient s (equation III) are coefficients that result from modeling light interaction with leaves (1). The coefficients s and k correspond to fractions of light that are scattered and absorbed respectively per unit of leaf area index.

Leaf thickness was measured with a linear-displacement transducer and digital voltmeter (10). Water content of leaves was determined on a dry-weight basis; leaves were oven-dried at 68 C for 48 h, and cooled in a desiccator before weighing.

Variance analysis and Duncan's multiple range test (13) were used on the spectrophotometric data for the selected wavelengths at 0.55, 0.65, and 0.85, 1.65, and 2.2-μm.

RESULTS AND DISCUSSION

Leaf characteristrics. These data are included to show the wide range of leaf thickness (0.122 to 0.235 mm), leaf water content (74.2 to 83.8%), and area per leaf (13.4 to 105.0 cm^2) represented by the weed species (Table 1). These data are used for descriptive and correlative purposes. The optical parameters represented the optical differences among leaves of the weed species.

Infinite reflectance $R\infty$. The highest reflectances and the largest interspecies differences were obtained at the 0.85-μm wavelength on the near-infrared reflectance plateau. The reflectances of common lambsquarters, johnsongrass, annual sowthistle, and Palmer amaranth were significantly larger ($p = 0.05$) than sunflower, ragweed parthenium, or London rocket (Table 2). These results were not consistent with leaf thickness and water content measurements (Table 1). High $R\infty$ was associated with more finely divided mesophyll structure, which was conducive to short path lengths of light and subsequently less light absorptance (2).

Absorption coefficient k. The largest k values were obtained at the 0.65-μm wavelength, which represent the chlorophyll absorption band in the red light region (Table 3). Annual sowthistle had the largest k value, and Palmer amaranth had the smallest k value at the 0.65-μm wavelength. Thus, annual sowthistle would probably cause the largest loss of insolation for photosynthetic activity of agriculturally useful plants. Reflectance measurements showed that annual sowthistle had a higher chlorophyll concentration than did Palmer amaranth (7, 8). Note that the k values at the 1.65- and 2.20-μm wavelengths are predominantly affected by the amount of water over a spectrophotometer's port (2). Reference to Table 1 shows that annual sowthistle leaves had a significantly higher water content, and were thicker than, Palmer amaranth leaves. These factors contributed to high k values for annual sowthistle in relation to those for Palmer amaranth at 1.65 and 2.20 μm. The reason for the larger k values for London rocket (1.65 μm) and common lambsquarters (2.20 μm) than for annual sowthistle are not known; London rocket and lambsquarter both had a lower water content that did annual sowthistle.

Scattering coefficient. In general, johnsongrass, ragweed parthenium, or London rocket had the larger s values among the five wavelengths, whereas annual sowthistle and Palmer amaranth were usually lowest (Table 4). The s values were not clearly associated with the leaf thickness and water content measurements in Table 2. It is known, however, that leaf structure causes light scattering, especially at the 0.85-μm wavelength in the near-infrared reflectance plateau region (1); on the average, the scattering coefficients at 0.85 μm (Table 4) were higher than at the other wavelengths. The scattering coefficient s is a function of leaf structure. If the leaves of all seven weed species had essentially the same internal structure, s would have been strongly correlated with leaf thickness. This was not true, so structure was important in light scattering.

Table 1. Mean leaf thickness, water content, and area per leaf for seven weed species. Each mean is based on 10 replications[a].

Species	Thickness	Water Content	Area per leaf
	(mm)	(%)	(cm^2)
Ragweed parthenium	0.236a	74.2d	56.6b
Common lambsquarters	0.235a	77.5c	13.4d
Wild common sunflower	0.234a	82.3ab	105.0a
Annual sowthistle	0.218b	83.8c	46.6bc
Palmer amaranth	0.166c	80.0bc	44.3c
Johnsongrass	0.145d	76.9cd	98.5a
London rocket	0.122e	78.8c	16.7d

[a]Means within each column followed by a common letter are not significantly different, p = 0.05, according to Duncan's multiple range test.

Table 2. Infinite reflectance for leaves of seven weed species at five wavelengths. Each coefficient is based on 10 replications[a].

Species	Wavelength (μm) 0.55	0.65	0.85	1.65	2.20
	(R_∞)				
Ragweed parthenium	13.28a	07.32b	68.94c	46.50a	25.30a
Common lambsquarters	12.33b	07.39b	93.32a	36.17cd	16.30bc
Wild common sunflower	11.20c	07.70b	81.96b	42.14b	19.83b
Annual sowthistle	10.26d	05.36c	90.85a	34.30d	14.90c
Palmer amaranth	12.14b	09.05a	90.75a	41.76b	18.52b
Johnsongrass	13.84a	08.59a	92.48a	46.57a	23.54a
London rocket	13.18a	07.37b	56.64d	38.54c	20.99a

[a]Means within each wavelength followed by a common letter are not significantly different, p = 0.05, according to Duncan's multiple range test.

Table 3. Absorption coefficients for leaves of seven weed species at five wavelengths. Each coefficient is based on 10 replications[a].

Species	Wavelength (m) 0.55	0.65	0.85	1.65	2.20
	(k)				
Ragweed parthenium	1.92a	4.45c	0.08b	0.25cd	0.66c
Common lambsquarters	1.71b	4.80bc	0.00c	0.34b	0.92a
Wild common sunflower	2.03a	4.25c	0.02c	0.29c	0.84ab
Annual sowthistle	1.87b	6.20a	0.01c	0.35ab	0.92a
Palmer amaranth	1.86ab	3.21d	0.01c	0.24e	0.69c
Johnsongrass	1.95a	5.56ab	0.03c	0.21e	0.62c
London rocket	1.95a	5.56ab	0.17a	0.38a	0.82b

[a]Means within each wavelength followed by a common letter are not significantly different, p = 0.05, according to Duncan's multiple range test.

Table 4. Scattering coefficients for leaves of seven weed species at five wavelengths. Each coefficient is based on 10 replications[a].

Species	Wavelength (m) 0.55	0.65	0.85	1.65	2.20
	(s)				
Ragweed parthenium	0.67a	0.75c	1.03a	0.81a	0.58a
Common lambsquarters	0.55bc	0.83bc	0.85bc	0.60d	0.43c
Wild common sunflower	0.58b	0.77c	0.93b	0.73b	0.52b
Annual sowthistle	0.48c	0.74c	0.83c	0.55d	0.38d
Palmer amaranth	0.58b	0.70c	0.82c	0.59d	0.39cd
Johnsongrass	0.73a	1.15a	0.88bc	0.68c	0.49b
London rocket	0.68a	0.95b	1.02a	0.77ab	0.52b

[a]Means within each wavelength followed by a common letter are not significantly different, p = 0.05, according to Duncan's multiple range test.

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