Contract No.:

This manuscript has been authored by Savannah River Nuclear Solutions (SRNS), LLC under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

Title: Desert Camouflage and What Wildlife See

Wendy W. Kuhne, Savannah River National Laboratory (SRNL), Aiken, South Carolina, 29808 USA, Wendy.Kuhne@srnl.doe.gov

Martine C. Duff, Savannah River National Laboratory (SRNL), Aiken, South Carolina, 29808 USA, Martine.Duff@srnl.doe.gov

Katie Salvaggio, Savannah River National Laboratory (SRNL), Aiken, South Carolina, 29808 USA, Katie.Salvaggio@srnl.doe.gov

Nancy V. Halverson, Savannah River National Laboratory (SRNL), Aiken, South Carolina, 29808 USA, Nancy.Halverson@srnl.doe.gov

Ronald Staggs, Savannah River National Laboratory (SRNL), Aiken, South Carolina, 29808 USA, Ronald.Staggs@srnl.doe.gov

Title: Desert Camouflage and What Wildlife See

Abstract

Desert, desert-scrub, savanna and sandy beach and lakeshore environments can be particularly tricky in terms of camouflage selection due to their low vegetative density. Therefore many companies focus on the development of paint color schemes that match the vegetation and the desert soils/sands. However another factor in the consideration of which camouflage to purchase may lie in what the animal can see. White-tailed deer and similar large mammals have been shown to have three classes of photo pigments that are sensitive to the range of blue to yellow-green during day light hours and blue to blue-green at night. Six commercially-available camouflage patterns were investigated to determine if the reflectance characteristics measured in the laboratory and under field conditions were elevated in the blue range and perhaps more likely to be seen by wildlife. The camouflage patterns were evaluated against standard vegetation indices including NDVI, SAVI, EVI, and SR. Only two of the patterns (S4 and S5) possessed a reflectance more like vegetation. Patterns S4, S6, S3, and S2 all showed only slight elevations in the blue wavelength range which could only have been detected by NIR measurements instead of visual observation by the human eye.

Keywords: camouflage, desert, blue wavelength, animals, NIR

Introduction

Desert, desert-scrub, savanna and sandy beach and lakeshore environments can be particularly tricky in terms of camouflage selection due to their low vegetative density. Therefore many companies focus on the development of paint color schemes for camouflage patterns that match desert vegetation and soil. However another factor in the consideration of which camouflage to purchase may lie in what the animal can see. Animals can see color just like humans, however the range of colors they can see, the clarity, and the light sensitivity is dependent on the physiology, positioning and anatomy of the eye [1-6].

An organism's ability to see and distinguish color is determined by the shape of the eye and the number or ratio of rods and cones in the retina [7]. Color vision is mostly driven by the cone photoreceptor pigments for which there are three types (S-, M-, and L-cones) that correspond to being able to perceive short-wavelength, medium-wavelength, and long-wavelength light. Mammals can poses only one cone pigment (monochromat) or three types of pigments (trichromat) making for optimum color vision [1, 8, 9]. Rods are best suited for dim light conditions and predominate in nocturnal species, whereas cones are for bright light conditions and are typically more predominate in diurnal species [9, 10].

White-tailed deer have two classes of cone photo pigments; the short-wavelength (blue)-sensitive pigment with a peak between 450 and 460 nm; a middle-wavelength (yellow-green)-sensitive photo pigment with a peak of 537 nm; and a rod-associated photo pigment at 497 nm [11]. While deer rely primarily on hearing and olfaction to monitor changes in their environment, they see colors in the range of blue to yellow-green during day light hours and see blue to blue-green at night [5]. Behavioral studies using various short- and long-wavelength light sources showed that deer have a greater perceptual sensitivity to shorter wavelengths and lower sensitivity to longer wavelengths. The enhanced sensitivity to short-wavelength light where the blue wavelengths are dominant [5] aids in their movement and detection of predators in low light/dusk conditions.

For terrestrial hunting of large game like deer and elk the typical hunting distance is between 30 to 50 yards—depending on the weapon used (bow or rifle). That short distance puts an importance on the camo having properties that closely mimic the natural vegetation. One feature of natural vegetation is in its distinctive reflectance and levels of chlorophyll. Chlorophyll is a necessary pigment that absorbs energy from sunlight and converts it to a usable chemical form of energy in the plant. Typically healthy vegetation shows strong absorption due to the chlorophyll between 400 to 700 nm with a peak of chlorophyll reflectance at 500 nm (blue) then a rapid and large rise in reflectance around 700 nm (red) and reflects strongly in green light. This rapid rise in reflectance is commonly referred to as the "red edge." Near Infrared (NIR) spectra of vegetation in wet, semi-arid, and arid ecosystems display a red edge [12]. While the magnitude of reflectance may differ the spectral feature is present. Vegetative indices (VI) have been developed in wavelength regions from 400 to 1100 nm to evaluate vegetation (i.e. health, percent cover) by ratios evaluating wavelengths in the NIR and the "red edge".

The purpose of this work was to evaluate several commercially-available camouflage patterns that are designed for desert-type environments for their reflectance in the visible and NIR using a spectroradiometer. In particular patterns will be evaluated against VIs and reflectance levels in key wavelength regions specific to deer and other large ungulates.

Materials and Methods

Instrumentation

Diffuse reflectance measurements were taken with an ASD Inc. FieldSpec Pro spectroradiometer (FSP 350-2500P; Analytical Spectral Devices (ASD), Boulder, CO). The FSP was set to measure in the Visible, Near Infrared (NIR) and Short-Infrared (SWIR) wavelengths and operates in the range of 350 to 2500 nm. It is a portable instrument with sampling intervals/spectral resolutions of 1.4/3 and 2/10 nm for 350 to 1000 nm and 1000 to 2500 nm respectively [13].

Field of view measurements

Field-of-View (FOV) spectra were collected using an 8° FOV optic where the optic was placed 24” above and at 45° from the surface of the pattern and positioned on a tripod to maintain the same position for each spectra. The height and position were checked between patterns to ensure positioning. Incident light was provided by two halogen lamps (Pro Lamp, 14.5 V, 50 W, Part No. 145378, ASD). Spectra were collected under dark room conditions where reflective surfaces were covered with light-absorbent material to minimize noise and spectral variability. Reference reflectance spectra were taken using a certified Spectralon® white panel (25.4 cm^2, LabSphere, North Sutton, NH) of 99% reflectance before and after each sample measurement.

Spectra were collected from three random locations on the pattern to address differences in color % represented in each FOV. Twenty-five scans were taken for each replicate spectra measurement for a total of 75 scans per sample.

Additional spectra were collected outdoors near Las Vegas, NV under ambient lighting conditions with a clear blue sky. Spectra were taken at 30” above the material at 45° using the 8° FOV optic.

Camouflage patterns

Camouflage patterns that were marketed as desert camo were obtained from commercial vendors. Patterns ranged from 5 to 10 m^2. Black felt was used as a control (**Table 1**).

Data analysis

The raw data of reflectance for each wavelength for each fabric was investigated using descriptive statistics using Origin Pro 2016 (OriginLabs). The data were examined for outliers and a Savitzky-Golay digital filter was applied.

Computation of spectral VIs

Vegetation indices provide a way to evaluate the reflectance properties in regards to the vegetation of the natural background. They have been derived to focus on particular wavelengths in the red and NIR regions and used to assess vegetation health. Three commonly used VIs (**Table 2**) are the Normalized Difference Vegetation Index (NDVI), the Simple Ratio (SR), and the Enhanced Vegetation Index (EVI). The Soil Adjusted Vegetation Index (SAVI) accounts for when soil reflectance contributes to the overall reflectance signal (**Table 3**). This is often true for desert environments where vegetation cover is sparse.

Results and Discussion

The camouflaged patterns in these experiments could be categorized as a solid 2-D material, a 3-D camouflage composite material with a net backing, or traditional net design where certain portions were open (i.e., see through). The colors represented on each fabric ranged from two to four individual colors ranging from light brown to dark green. The pigmentation texture ranged from smooth and shiny to bumpy and rough.

The first evaluation of the patterns was performed in reference to typical reflectance patterns for healthy vegetation, which show a strong reflectance between 400 and 700 nm due to chlorophyll pigmentation. Chlorophyll peaks appear at 500 nm (blue) and then a rapid and large rise in reflectance ~700 nm (red) reflects strongly in green light. This feature is known as the "red edge" which occurs between the near and infrared (~700 and 745 nm). Chlorophyll in the leaf cells absorbs light mostly the visible range but it becomes almost transparent at wavelengths exceeding 700 nm. At this region the cellular structure of the leaf functions as a reflector and changes the reflectance from 5% to ~50% between 680 to 730 nm [14]. High reflectances between 700 and 1300 nm are primarily due to the internal leaf structure [15]. Light is scattered at the interfaces of cell walls and intercellular air spaces [16] and influenced by mesophyll cell surface area and intercellular air spaces [17-19]. Visual inspection of the spectra from 400 to 900 nm showed that two of the six camouflage materials investigated displayed the "red edge" as compared to a model terrestrial plant species called *Arabidopsis thaliana* or thale cress. The characteristic "S" shape spectral feature appeared in the lab and field collected measurements for camouflage S4 and S5 (**Figure 1**). Comparison of the mean reflectance for all camouflages ranged from 0.17 to 0.37 (**Table 3**).

The NDVI calculation for S4 and S5 indicated the spectra resembled healthy green vegetation. The SR index for the S4 lab and field spectra were indicative of healthy green material but only the lab spectra for camouflage S5 were indicative of a healthy SR index. One potential reason for the difference in the lab and the field collected spectra could be due to the time of day that the measurements were taken. Despite clear-sky conditions, the spectra were collected after solar noon and the change in the solar zenith angle could have influenced the measurement as reported by others [20]. The remaining camouflage patterns did not mimic green healthy vegetation based on these two indices.

The EVI was developed as an alternative to the NDVI to be more sensitive to changes in areas having high biomass, reduce the influence of atmospheric conditions on VI values, and correct for canopy background signals. According to the EVI, the lab and field spectral reflectance values for camouflage S4 and S5 were consistent with green healthy vegetation.

The SAVI is a modification to the NDVI that account for areas where vegetative cover is low (i.e. < 40%) and the soil surface generally exposed. The subsequent reflectance of light in the red and NIR spectra could influence the VI values. This could be particularly true for desert environments with sparse and fragmented vegetation. At a soil brightness correction value of 0.5 (for moderate vegetation cover), only S4 and S5 mimicked green healthy vegetation based on the all measurements (**Table 4)**.

Evaluation of Blue and Green Wavelengths

Deer and other ungulates have specific photo pigments in the blue (450 to 500 nm) and green (500 to 570 nm) ranges. White-tail deer in particular have a middle-wavelength (yellow-green) sensitive photo pigment with a peak of 537 nm and a rod associated photo pigment with a peak of 497 nm [5]. In the blue wavelength region of 450 to 500 nm camouflage S3 and S4 had the lowest reflectance for all field measurements (0.09 and 0.06 respectively) (**Table 5**).

A first derivative of the original laboratory spectra was acquired to identify reflectance and absorption peaks in these regions (450 to 500 nm) (**Figure 2**). Initial evaluation of the first derivative spectra showed subtle reflectance peaks for patterns S2, S3, S4 and S6 that occurred between 500 and 525 nm. Patterns S2 and S6 also had a reflectance peak near 575 nm. Inspection of the photo pigment peak at 497 and 537 nm reveals that S1, S5 and S6 had their highest reflectance values at these wavelengths (**Table 6**).

Conclusions

During hunting and wildlife viewing activities desert environments are particularly challenging due to the limited numbers and low stature of green lush vegetation in which to hide behind. Therefore hunters in these environments need camouflage materials to match the background environment without having incidental reflectance in the visible that are best viewed by the prey species. For example, deer and other large ungulates like antelope, cattle and horses have specific photo receptors for the colors blue and yellow-green whereas predators like humans and bears see in more colors. In this paper six commercially available desert camouflages were purchased and tested for reflectance in the visible and NIR wavelength ranges. Only two of the camouflages (S4 and S5) were considered to mimic green vegetation based on their NDVI, SR, EVI and SAVI (0.5). Camouflages S1, S2, S3, and S6 showed slight reflectance increases for 497 and 537 nm in the blue wavelength range, which might make them visible to wildlife.

Many companies offer guides to assist in the selection of camo patterns by geographic region. Results of this work indicate that while camo designed for a specific geographic region, desert environment, could blend well with the color pallets and vegetation types encountered in the region, the spectral properties embedded in the paints, dyes and patterns used could instead highlight visible regions of light that the species of interest see well. The use of NIR spectroradiometer measurements could prove useful in the selection of camo for your next hunting or wildlife viewing trip.

Acknowledgements

This project was conducted in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Dept. of Energy. This work was supported by the SRNL Laboratory-Directed Research and Development Program.

References

1. Banks MS, Sprague WW, Schmoll J, Parnell JAQ and Love GD. Why do animal eyes have pupils of different shapes? *Science Advances*. 2015; 1: 1-9.
2. Jonasova K and Kozmik Z. Eye evolution: Lens and cornea as an upgrade of animal visual system. *Seminars in Cell & Developmental Biology*. 2008; 19: 71-81.
3. Jones MP, Pierce KEJ and Ward D. Avian vision: A review of form and function with special consideration to birds of prey. *Journal of Exotic Pet Mecidine*. 2007; 16: 69-87.
4. Valera FJ, Palacios AG and Goldsmith TH. Color vision of birds. In: Ziegler HP and Gischof H-J, (eds.). *Vision, Brain, and Behavior in Birds*. Cambridge, MA, MIT Press1993, p. 77-98.
5. VerCauteren KC and Pipas MJ. A review of color vision in white-tailed deer. *Wildlife Society Bulletin*. 2003; 31: 684-91.
6. Wintersteen K. How ducks see: The science behind waterfowl eyesight. 4 October 2013. *Outdoor Life*. Available at: https://www.outdoorlife.com/blogs/master-class/2013/10/how-ducks-see-science-behind-waterflowl-eyesight (2013, accessed 10 July 2017).
7. Medeiros JA and Medeiros NE. The Shape of Color: Retinal Cones and Spectral Dispersion. *Peer Journal PrePrints*. 2014; 1: 1-32.
8. Bowmaker JK. Evolution of colour vision in vertebrates. *Eye*. 1998; 12: 541-554.
9. Müller-Schwarze D. The senses of deer. In: Gerlach D, Atwater S and Schnell J, (eds.). *The Wildlife Series: Deer*. Mechanicsburg, PA; Stackpole Books, 1994.
10. Ali MA and Klyne MA. *Vision in vertebrates*. New York: Plenum Press. 1985.
11. Jacobs GH, Deegan JEI, Neitz J, Murphy BP, Miller KV and Marchinton RL. Electrophysiological measurements of spectral mechanisms in the retinas of two cervids: white-tailed deer (*Odocoileus vfrginlanus*) and fallow deer (*Dama dama*). *Journal of Comparative Physiology*. 1994; A 174: 551-557.
12. Clark RN, Swayze GA, Gallagher AJ, King TVV and Calvin WM. The U.S. Geological Survey, Digital Spectral Library: Version 1: 0.2 to 3 microns. U.S. Geological Survey, Open File Report 93-952. 1340p. 1993.
13. (ASD) ASD. FieldSpec$^{(R)}$ Pro: User's Guide ASD, 2002.
14. Seager S, Turner EL, Schafer J and Ford EB. Vegetation's red edge: A possible spectroscopic biosignature of extraterrestrial plants. *Astrobiology*. 2005; 5: 372-390.
15. Slaton MR, Jr. Hunt R and Smith WK. Estimating near-infrared leaf reflectance from leaf structural characteristics. *American Journal of Botany*. 2001; 88: 278-284.
16. Gausman HW, Allen WA and Cardenas R. Reflectance of cotton leaves and their structure. *Remote Sensing of Environment*. 1969; 1: 19-22.
17. Knipling EB. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. *Remote Sensing of Environment*. 1970; 1: 155-159.

18. Terashima I and Saeki T. Light enviornment within a leaf I. Optical propoertites of paradermal sections of *Camellia* leaves with special reference to the differences in the optical properties of palisade and spongy tissues *Plant and Cell Physiology*. 1983; 24: 1493-1501.
19. Delucia EH and Nelson KP. Contribution of internal reflectance to light absorption and photosynthesis of shade leaves. *Bulletin of the Ecological Society of America*. 1993; 74: 211-212.
20. Habte A, Andreas A, Ottoson L, et al. Indoor and outdoor spectroradiometer intercomparison for spectral irradiance measurement. Report, National Renewable Energy Laboratory. NREL/TP-5D00-61476, May 2014, pp. 1-21.
21. Rouse JW, Haas RW, Schell JA, Deering DW and Harlan JC. Monitoring the vernal advancement and retrogradiation (greenware effect) of natural vegetation. Greenbelt, MD: NASA/GSFCT, 1974.
22. Jordan CF. Derivation of leaf-area index from quality of light on forest floor. *Ecology*. 1969; 50: 663-666.
23. Huete AR, Justice C and van Leeuwen W. MODIS vegetation index (mod13). Algorithm theoretical basis document. Version 2. Greenbert, MD: NASA Goddard Space Flight Center, 1996.
24. Huete AR, Liu HQ, Batchily K and van Leeuwen W. A comparison of vegetation indices global set of TM images for EOS-MODIS. *Remote Sensing of Environment*. 1997; 59: 440-451.
25. Huete AR. A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*. 1988; 25: 295-309.

Table 1. Commercially obtained desert camouflage pattern characteristics.

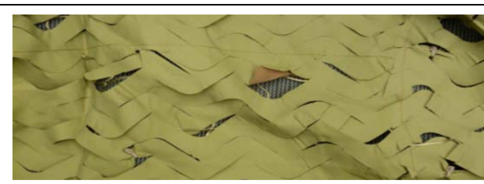
Sample ID	Procurement Information	Colors	Image
S1	SAAB Barracuda, LLC, Lillington, NC	Clay, Green, Sand	
S2	Holy Monkey, Inc., Hesperda, CA	Brown, Light Brown	
S3	Rakasha Supreme Camouflage, New Delhi, India	Light Brown, Dark Brown, Black Netting	
S4	HIFA, China	Light Green, Dark Green, Olive, Sand	
S5	China	Sand, Light Brown, Brown	
S6	China	Light Brown, Copper	

Table 2. Vegetation indices.

Vegetation Indices	**Equation**	**Reference**
Normalized Difference Vegetation Index (NDVI)	$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$	21
Simple Ratio (SR)	$SR = \frac{\rho_{NIR}}{\rho_{Red}}$	22
Enhanced Vegetation Index (EVI)	$EVI = 2.5 \frac{\rho_{NIR} - \rho_{Red}}{1 + \rho_{NIR} + 6\rho_{Red} - 7.5\rho_{Blue}}$	23, 24
Soil Adjusted Vegetation Index (SAVI) Where L= 0.5 for intermediate vegetation cover	$SAVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red} + L}$	25

Table 3. Mean reflectance values between 400 and 900 nm.

Sample	Lab Mean	Lab SE	Field Mean	Field SE
Felt	0.02	0.0002		
S1	0.26	0.02	0.32	0.01
S2	0.17	0.02	0.22	0.03
S3	0.19	0.003	0.17	0.01
S4	0.20	0.02	0.14	0.02
S5	0.37	0.03	0.32	0.04
S6	0.23	0.02	0.21	0.02

Table 4. Vegetation indices results.

Vegetation Index	Factor	Lab Mean	Lab SE	Lab F-value	Lab p-value	Field Mean	Field SE	Field F-value	Field p-value
NDVI	Felt	0.06	-0.08	2.5	<0.001				
	S1	0.18	0.45			0.12	0.01	2.9	<0.001
	S2	0.06	0.03			0.10	0.002		
	S3	0.06	0.80			0.05	0.006		
	S4	**0.48**	**0.46**			**0.45**	**0.10**		
	S5	**0.56**	**0.67**			**0.24**	**0.01**		
	S6	-0.02	-0.04			0.005	0.005		
SR	Felt	1.12	0.84	2.5	<0.001				
	S1	1.44	1.34			1.28	0.03	2.9	<0.001
	S2	1.12	1.05			1.22	0.004		
	S3	1.14	8.52			1.11	0.01		
	S4	**2.88**	**2.69**			**2.88**	**0.61**		
	S5	**3.55**	**5.00**			1.63	0.05		
	S6	0.62	0.13			1.01	0.01		
EVI	Felt	0.01	-7.6E-5	2.5	<0.001				
	S1	0.16	0.02			0.12	0.03	2.9	<0.001
	S2	0.04	0.001			0.08	0.01		
	S3	0.04	0.01			0.03	-0.001		
	S4	**0.38**	**0.05**			**0.30**	**0.04**		
	S5	**0.62**	**0.13**			**0.25**	**0.07**		
	S6	-0.02	-0.006			0.003	-0.002		
SAVI (0.5)	Felt	0.004	-6.1E-5	2.5	<0.001				
	S1	0.10	0.01			0.08	0.02	2.9	<0.001
	S2	0.02	0.002			0.05	0.01		
	S3	0.03	0.01			0.02	-0.001		
	S4	**0.25**	**0.04**			0.19	0.03		
	S5	**0.36**	**0.10**			0.14	0.06		
	S6	-0.01	-0.004			0.002	-0.002		

Table 5. Means for reflectance for wavelengths in the blue and green regions.

	450 to 500 nm Mean (SE)		500 to 570 nm Mean (SE)	
Sample	**Lab**	**Field**	**Lab**	**Field**
S1	0.16 (0.01)	0.20 (0.01)	0.20 (0.01)	0.24 (0.01)
S2	0.11 (0.01)	0.14 (0.01)	0.16 (0.02)	0.19 (0.02)
S3	0.09 (0.003)	0.09 (0.006)	0.15 (0.01)	0.14 (0.01)
S4	0.07 (0.005)	0.06 (0.004)	0.11 (0.01)	0.08 (0.01)
S5	0.12 (0.01)	0.18 (0.02)	0.16 (0.01)	0.23 (0.03)
S6	0.16 (0.02)	0.15 (0.02)	0.23 (0.02)	0.20(0.02)

Table 6. Field and lab reflectance measurements at wavelengths 497 nm (Blue) and 537 nm (Green)

Sample	Lab Reflectance at 497 nm	Field Reflectance at 497 nm	Lab Reflectance at 537 nm	Field Reflectance at 537 nm
S1	0.17	0.21	0.20	0.01
S2	0.12	0.15	0.17	0.19
S3	0.10	0.10	0.16	0.15
S4	0.08	0.07	0.11	0.08
S5	0.13	0.20	0.16	0.23
S6	0.17	0.15	0.25	0.22

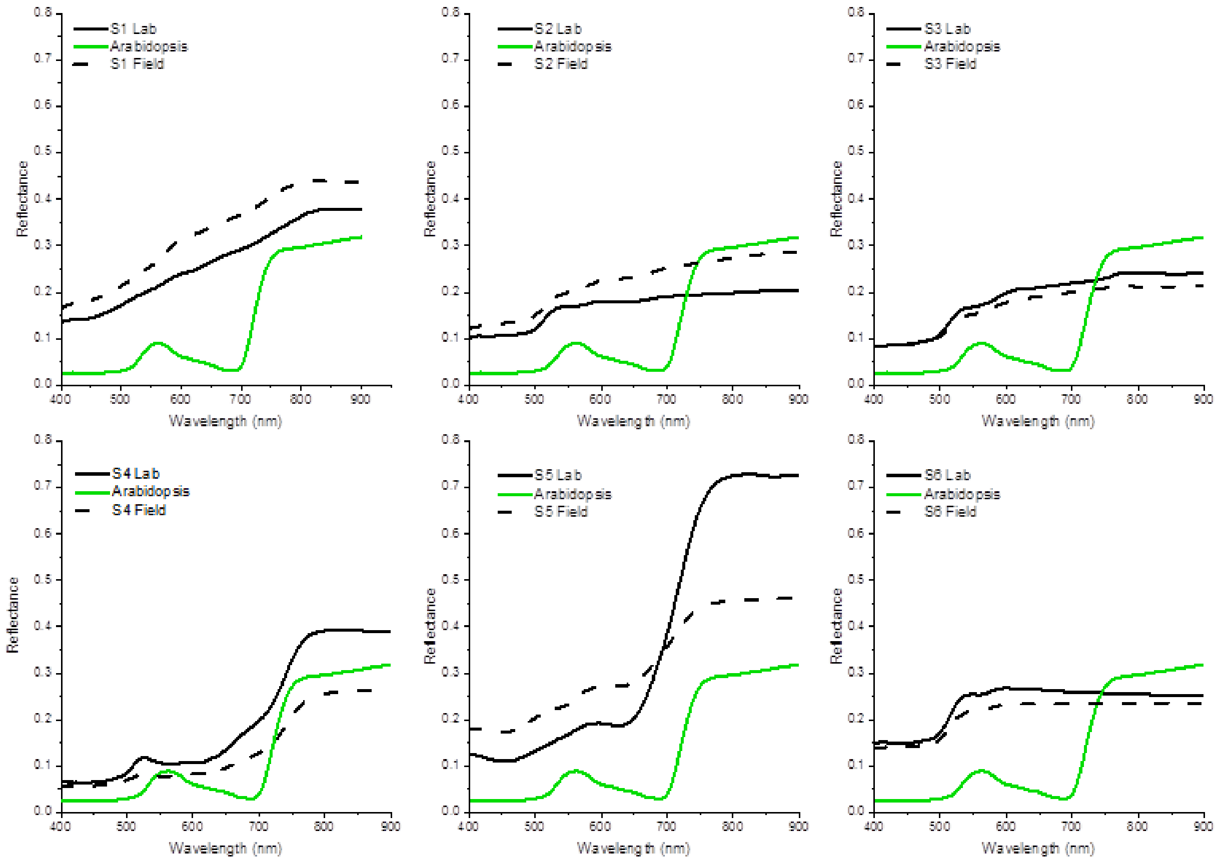


Figure 1. Relative reflectance spectra.

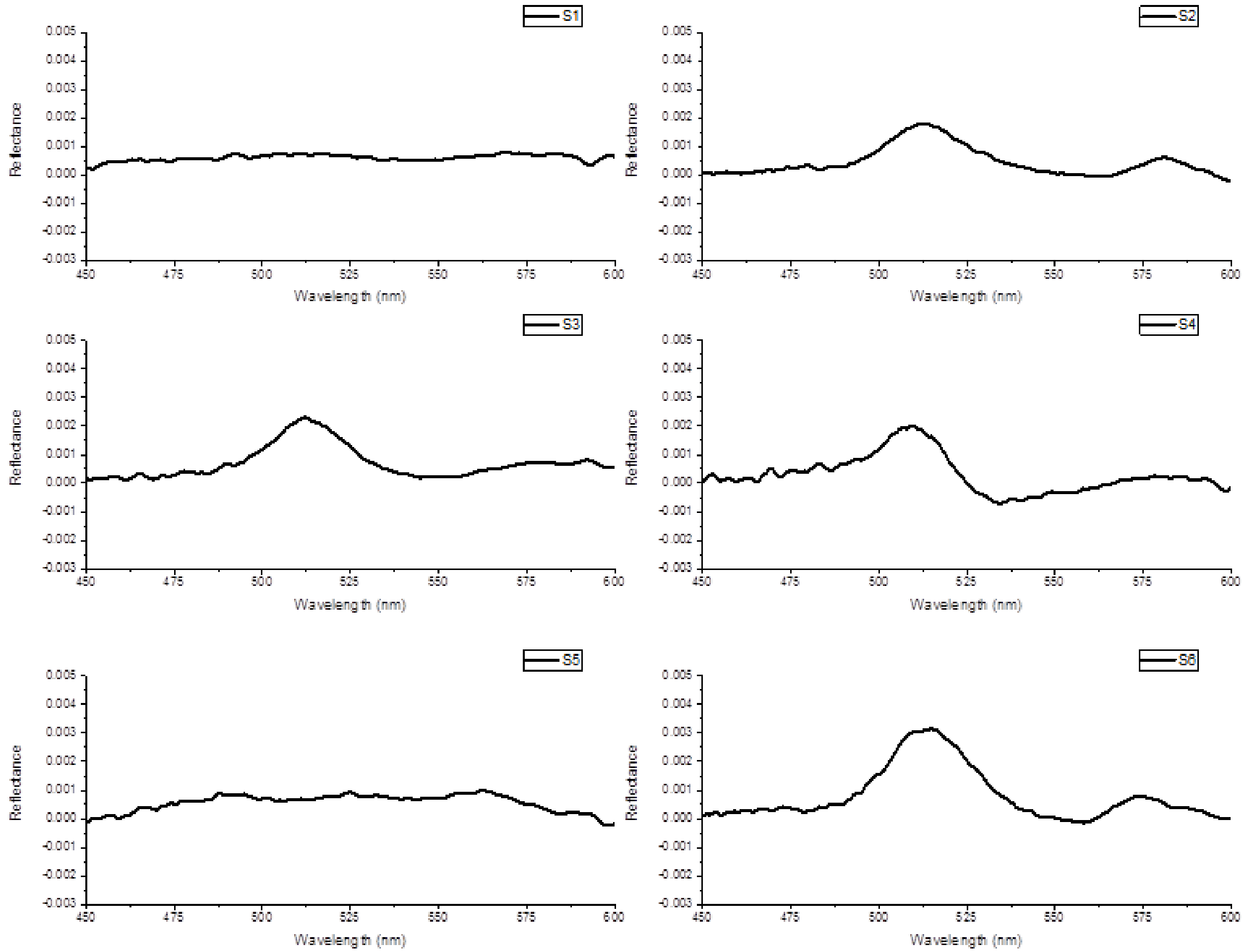


Figure 2. First derivative of lab derived spectra.