Aim of Lesson

To distinguish different vegetation species by their leaf reflectance spectra and to use different indices to characterize these differences.

Objectives

1. To learn how to use the FieldSpec Pro FR (ASD) field spectroradiometer, combined with the contact probe, to measure leaf reflectance.
2. To learn how different leaf reflectance spectra vary according vegetation species.
3. To calculate different vegetation indices for observing species specific parameters and leaf chemical properties.

Background Information

Practical issues

First you will learn how to carry out leaf reflectance measurements. Therefore, from three different plant species, three randomly chosen healthy leaves are selected for in-vivo reflectance measurements with the FieldSpec Pro FR (ASD) field spectroradiometer combined with the contact probe. Next, you will observe the differences in reflectance spectra between different plant species and the difference in reflectance spectra between leaves of the same species. Finally, you will learn how the differences in reflectance spectra can be measured by different vegetation indices.
This lesson relates to the Sections 5.2, 12.1 and 12.2.4 of the HyperTeach Theory Syllabus. For further details about the instruments or techniques involved readers are recommended to read these sections. The measurement procedure for the FieldSpec Pro FR (ASD) and contact probe is described in the ANNEX of the HyperTeach Theory Syllabus.

Software

A PC with ENVI® software and Microsoft Excel is required to carry out the lesson.

Lesson outline

Leaf reflectance measurement

In this section you will learn why healthy leaves appear green to the human eye and how the green colour is related to the measured reflectance spectrum. The FieldSpec Pro FR (ASD) field spectroradiometer, combined with the contact probe, is used to measure reflectance spectra from three different plant species. To simplify the interpretation of the measured reflectance spectra, you should choose plant species which look different in colour to the human eye. If possible choose also a red-coloured species.

Measurement protocol

Because extensive field spectroradiometer measurements can lead to confusion, it is important to write down the measurements which are performed in chronological order. In the annex at the end of this lesson, a measurement protocol sheet is included as an example.

Choose three different plant species to carry out the measurements. From each species you randomly select three healthy leaves. Repeat the measurement sequence below three times for each leaf:

- Perform the first measurement on the reference panel
- Perform the next four measurements on different leaf locations

Make sure the measurements are performed in 'RAW digital number' mode (RAW DN), this means that the leaf reflectance has to be calculated afterwards. This can be done by dividing the measured leaf radiance value by the measured reference panel radiance:

$$Leaf\ reflectance = \frac{Leaf\ reflected radiance}{Reference panel\ reflected radiance} \qquad (9.1)$$

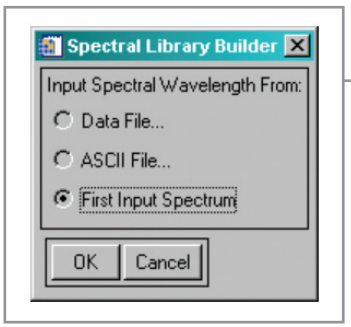
An example of leaf measurements can be found in the data directory: \Lesson09\Data\ASD_raw/*.*. We will use this dataset to show how the "raw" data can be used to create a spectral library containing the reflectance spectra of three common indoor plant species. The three species used are: Ficus Sp., Hedera Sp. and Yucca Sp.

Raw data handling

When all spectroradiometer measurements are done, we will use ENVI to build a spectral library from the raw data.

Action: In the 'ENVI' main menu use the 'Spectral Library Builder' option to open the ASD raw data files. Use this data to build a spectral library containing the reflectance spectra.

Hint: In the ENVI main menu [ENVI] use: <Spectral> <Spectral Libraries> < Spectral Library Builder>; in the' Spectral Library Builder' window switch-on the 'First Input Spectrum' radio button as shown in Figure 9.1 and click 'Ok'.

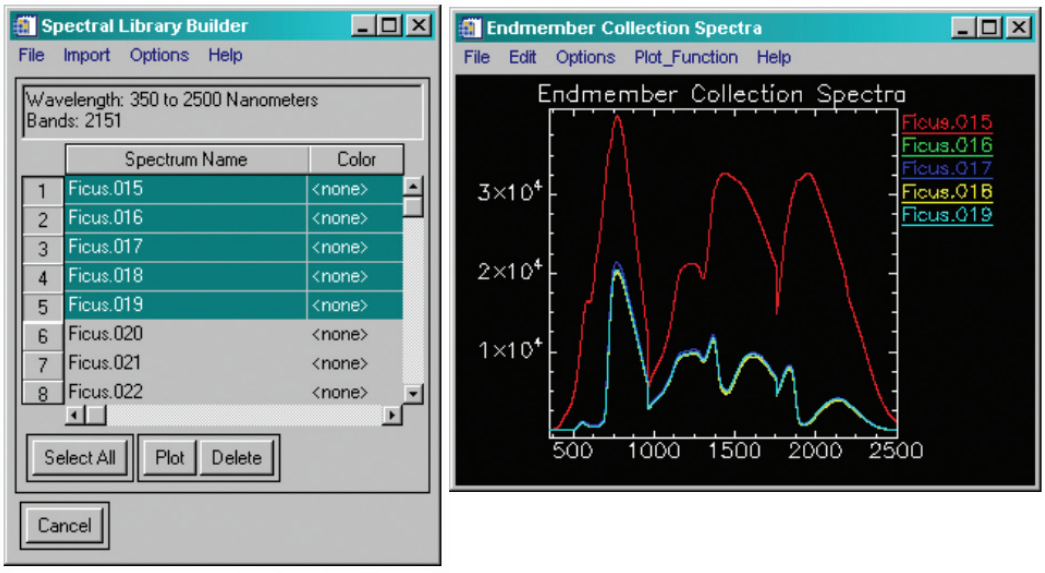


>> Figure 9.1: In the 'Spectral Library Builder' window, the 'First Input Spectrum' radio button has to be set when importing the raw ASD spectra.

Now you get the 'Spectral Library Builder' window. In this window use <Import> <from ASD binary file…> to import the ASD raw data from disk. Select all ASD files for import. After that your 'Spectral Library Builder' window will show a list of the ASD files.

Action: Visualize the ASD raw data and explore the measured spectra.

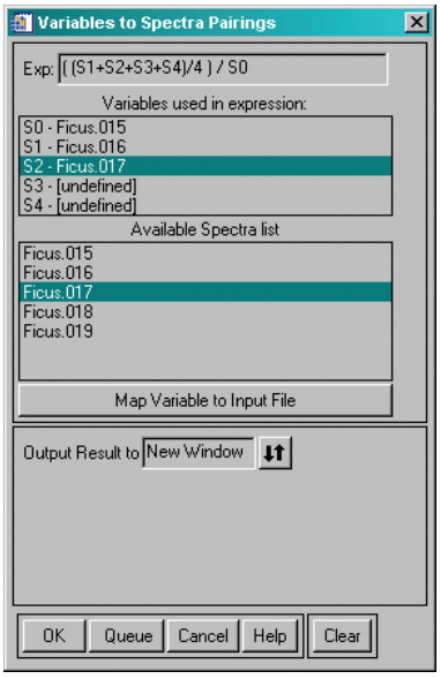
Hint: In the 'Spectral Library Builder' window, highlight the first five spectra, as shown in Figure 9.2 and click the 'Plot' button. In the 'Endmember Collection Spectra' window, right click the mouse and choose 'Plot Key' to show the names of the different spectra. Your 'Endmember Collection Spectra' window will now look as shown in Figure 9.2 (right).



>> Figure 9.2. Via the 'Spectral Library Builder' window, the raw ASD data can be imported into ENVI. Highlight the spectra and use the 'Plot' button to display the corresponding spectra.

Action: Calculate the reflectance spectrum for every measured leaf by using the 'Spectral Math' function.

Hint: For each leaf, you first measured the reference panel and subsequently four different locations on the leaf. When calculating the reflectance spectrum, the four leaf measurements have to be averaged. The leaf reflectance is defined according to formula (1) and can be calculated using the 'Spectral Math' option in the ENVI main menu. In the ENVI main menu [ENVI] use: <Basic Tools> <Spectral Math> and enter the expression: "((S1+S2+S3+S4)/4) / S0" and click 'Ok'. You will now see a window, 'Variables to Spectra Pairings', as shown in Figure 9.3:



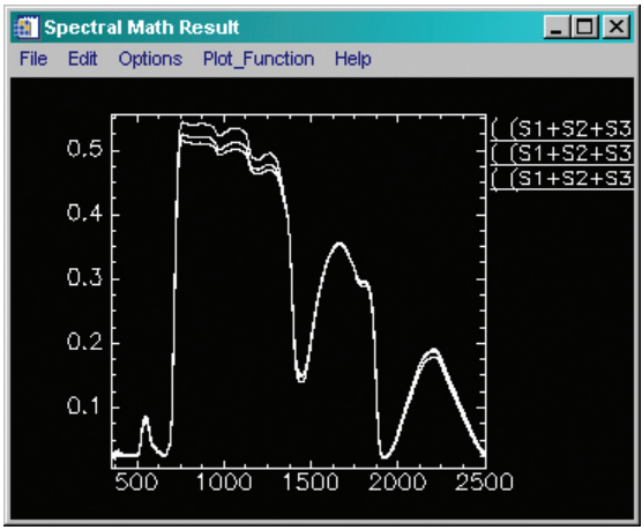
>> Figure 9.3: Via the 'Spectral Math' option in ENVI some basic calculations can be performed on the collected spectra. Use the 'Variables to Spectra Pairings' window to assign the different spectra to the different variables of the entered formula.

Make sure you map the correct spectrum from the 'Available Spectra list' (just highlight) to the correct 'Variables used in expression' (again highlight). In Figure 9.3 this can be seen for the 'Ficus.017' spectrum, which is matched with S2 variable of the formula. Also make sure that the measured reference panel spectrum is mapped to S0. Once all spectra are assigned to the formula variables the average reference spectrum can be calculated by clicking 'Ok'. Make sure you select 'New Window' to output the calculated reflectance spectrum.

! **Remark**: In the 'Available Spectra list' of the 'Variables to Spectra Pairings' window, you will only find the spectra which have been displayed via the 'Spectral Library Builder' as explained earlier. You can list all spectra in the 'Available Spectra list' by clicking 'Select All' followed by 'Plot' in the 'Spectral Library Builder' window.

Action: Calculate the reflectance spectrum for the remaining leaves of the same plant species by using the 'Spectral Math' module.

Hint: Use <Spectral Math> with the same formula as before to calculate the average reflectance spectra of the two remaining leaves of the same species. You can move the newly calculated average spectrum to the same plot window as the first calculated average spectrum. Grab the spectrum by its spectrum name using the right mouse button and drag it to the correct window. The plot window will now look as shown in Figure 9.4:



>> Figure 9.4 : The 'Spectral Math Window' was used to collect the average spectrum of three different leaves.

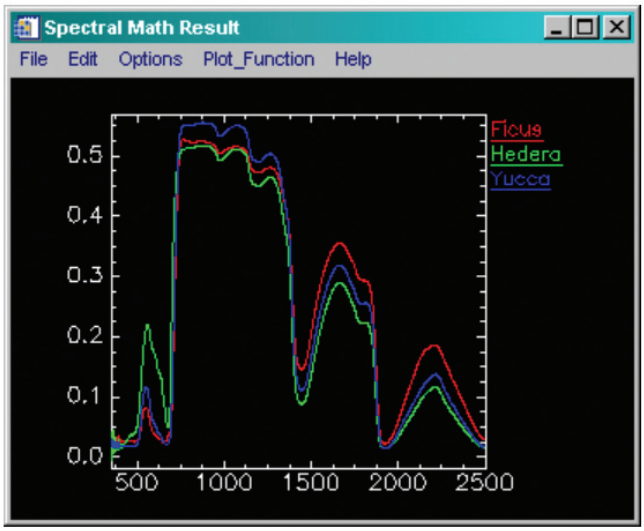
Action: Calculate the average reflectance spectrum of the three leaves of the same plant species by using 'Spectral Math'.

Hint: Use <Spectral Math> and enter the formula: (S1+S2+S3)/3. Use this formula to calculate the average reflectance spectrum.

! Remark: In the 'Spectral Math Result' window you can change name and colour of the spectrum via <Edit> <Data Parameters…>. Change the name to 'Ficus' and give the spectrum a 'Red' colour.

Action: Repeat this sequence to obtain the reflectance spectra of the two other plant species. Give them the corresponding names 'Hedera' and 'Yucca', with colours green and blue respectively.

Hint: When you arrived at this stage without to many problems, you are considered as an experienced 'hyperspectral image processing' operator! Try to build the plot shown in Figure 9.5.



>> Figure 9.5: The 'Spectral Math Result' window was used to collect the average spectrum of the three different plant species, Ficus Sp., Hedera Sp. And Yucca Sp., which were measured in the lab.

These spectra can also be found in the data directory where it is saved as a spectral library named: \Lesson09\Data\ASD_spec\Plant_Species_Lib.

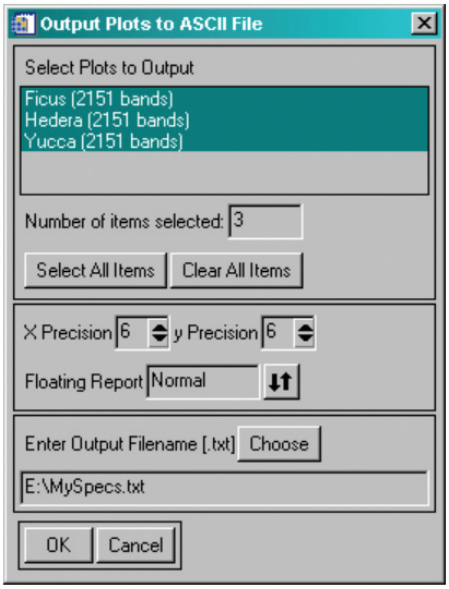
Question 9.1: You now have visualized the reflectance spectra of three different plant species. Can you deduce from the measured spectra the colour of the leaves as seen by the human eye?

Calculating different vegetation indices

Once the measured reflectance spectra are stored in a spectral library, they can be used to calculate different vegetation indices. The best and easiest way to do this is by saving the spectra to a text file and importing these into Microsoft Excel.

Action: Save the spectra to a text file and import it in Microsoft Excel.

Hint: Spectra can be saved to a text file via the "Spectral Math Results" or "Spectral Library Plots" window. Use: <File> <Save Plot As> <ASCII…> to save the spectra to a text file. This text file can be imported in Excel, using the import utility: <file> <open>. Once loaded, the data can easily be used to calculate different vegetation indices. Figure 9.6 shows how the spectra are saved in a text file.



>> Figure 9.6: The 'Output Plots to ASCII File' window is used to save the calculated spectra to an ASCII text file.

Numerous vegetation indices retrieved from the reflectance spectrum are studied for all kinds of applications. This lesson will focus on only five of them:

- 'Normalized Difference Vegetation Index' (NDVI)
- The reflection value at the inflection point ($R_{red\ edge}$)
- The wavelength at the inflection point ($R_{red\ edge}$)
- Chlorophyll content 1
- Chlorophyll content 2

More info on vegetation indices can be found in the HyperTeach Theory Section 12.2.4.

The 'Normalized Difference Vegetation Index' (NDVI) is a widely used canopy greenness indicator which is calculated as:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{9.2}$$

Use the reflectance value at wavelength 676 nm for RED and 776 nm for NIR.

Generally the red-edge is convexo-concave. The wavelength at which the concave shape changes into the convex shape is called the red-edge inflection point. Each vegetation species has its own specific red-edge inflection point and can change (i.e. a blue shift) when vegetation is stressed (e.g. by drought or heavy metals). The exact location of the inflection point can be calculated by an inverted Gaussian model which is rather complex. For this lesson we will use a more simplified method (Guyot G. et al., 1988):

First the reflection at the inflection point is calculated as:

$$R_{red\ edge} = \frac{(R_{670} + R_{780})}{2} \tag{9.3}$$

Where R_i stands for the reflectance value at wavelength i.

Subsequently a linear interpolation is used to estimate the wavelength corresponding to the reflectance at the inflection point:

$$\lambda_{red\ edge} = 700 + 40 * \left(\frac{R_{red\ edge} - R_{700}}{R_{740} - R_{700}} \right) \tag{9.4}$$

The typical vegetation spectral reflectance curve is caused by absorption at specific wavelengths, caused by different leaf pigments, mainly chlorophyll. Different ratios of reflectance values at specific wavelengths correlate with the chlorophyll content (Gitelson A.A. et al., 2003)

$$Chlorophyl\ content\ 1 \approx \frac{R_{750}}{R_{700}} - 1 \quad (9.5)$$

$$Chlorophyl\ content\ 2 \approx \frac{R_{750}}{R_{550}} - 1 \quad (9.6)$$

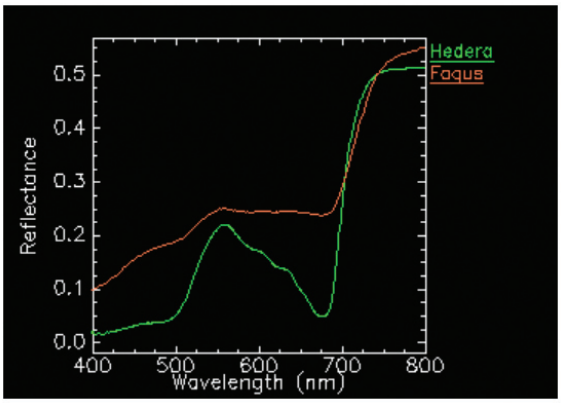
Action: Import the measured reflectance spectra into Excel and calculate the different vegetation indices NDVI, $R_{red\ edge}$, $\lambda_{red\ edge}$ and the chlorophyll content indices.

Question 9.2: Can you interpret the calculated values obtained by the different indices?

Answers to questions

Answer 9.1.: Can you deduce from the measured spectra the colour of the leaves as seen by the human eye?

Absorption by higher plants is strongest in the blue (400 – 500 nm) and red part (600 – 700 nm) of the visible spectrum. The green part (500 – 600 nm) of the spectrum is less absorbed by healthy leaves and this is the reason why they look green to the human eye. Some species, like red beech (Fagus Sp.), have dark red-brownish coloured leaves due to a decreased absorption in the red part (600 – 700 nm) of the spectrum, they possess a different leaf pigment composition. These phenomena can be observed in Figure 9.7.



>> Figure 9.7: Spectral plot showing a spectrum of a green leaved vegetation species (Hedera Sp.) versus a red leaved vegetation species (Fagus Sp.).

Answer 9.2: Can you interpret the calculated values obtained by the different indices?

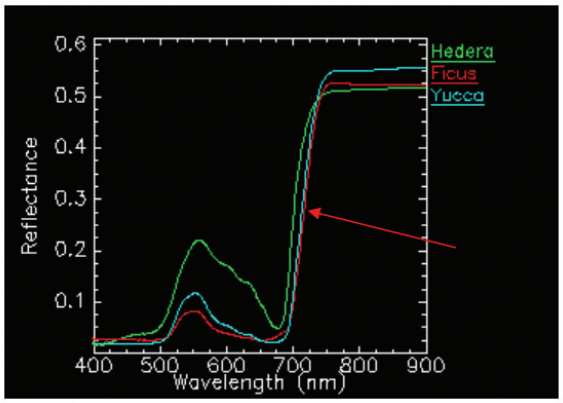
Table 9.1 shows five different vegetation indices calculated for the example spectra in \Lesson09\Data\ASD_spec\Plant_Species_Lib.

		Ficus	Hedera	Yucca
NDVI		0.880	0.826	0.923
Red-Edge reflectance		0.277	0.283	0.286
λ Red-Edge		718.2	703.4	717.0
Chlorophyll content	R750/R700 – 1	4.4	0.9	3.6
	R750/R550 – 1	5.3	1.4	3.6

>> Table 9.1. Five different vegetation indices were calculated for the three vegetation species.

The canopy greenness indicator, which is represented by the NDVI value, clearly differs for the different plant species. This value reflects the red-edge leap which is typical for vegetation, i.e. a large NDVI value indicates a large red-edge leap. In the example spectra, Yucca has the largest NDVI value (0.92), while Ficus has the smallest NDVI value (0.88). These values correspond with the size of the red-edge leap as can be seen in the spectral plot in Figure 9.8 (red arrow).

Different vegetation species have their own specific reflectance (Red-Edge reflection) and wavelength (Red-Edge) value at the red-edge inflection point. These values also depend on external stress factors (e.g. drought, heavy metal uptake) and can therefore be used for vegetation stress detection.
The absorptions in the blue and red part op the spectrum are mainly determined by the chlorophyll content of the leaves. Both 'chlorophyll content indices' show high chlorophyll concentrations in Ficus, less in Yucca and the lowest concentration in Hedera.



>> Figure 9.8: Plot window showing part of the vegetation reflectance spectra between 400 nm and 900 nm.

Related papers

Gitelson A.A., Gritz Y., Merzlyak M.N., 2003, Relationships between leaf chlorophyll content and spectral reflectance and algorithms for non-destructive chlorophyll assessment in higher plant leaves. Journal of plant physiology. 160 : 271-282.

Guyot G. and Baret F., 1988, Utilisation de la haute résolution spectrale pour suivre l'état des couverts végétaux. Proceedings of the 4th International Colloquium on Spectrale Signatures of Objects in Remote Sensing. ESA SP-287, Aussois, France : 279-286.

Annex

ASD Fieldspec FR3 **Data Log**

PC : Toshiba Libretto + IBM Thinkpad

Software = RS² - Version 2.11 + RS² - Version 2.3

ASD No.	6165 (=1)
Sheet No.	1

Site	Labo	Reference Panel	Spectralon 100%					
Date	24/02/2005	Fore Optic	~~1°~~	~~5°~~	~~5°~~	~~18°~~	~~COS~~	~~None~~
Operator	MR & JM	Illumination						
Instrument On	13:30	Mode	Raw DN		Radiance		Recflectance	
Directory	C:\ASD\PlantSpecies	Configuration	Spectrum: 10		DC: 25		WR: 10	

Time	Opt	DC	WR	Filename		Description	Sky	Processed Filename
				Root	Ext			
Meting met PC: Toshiba Libretto - RS² Version 2.11								
	x		x	Hedera	000	Spectralon panel		
				"	002	Leaf 1		
				"	003	Leaf 1		
				"	004	Leaf 1		
			x	"	005	Spectralon panel		
				"	006-009	Leaf 2		
			x	"	010	Spectralon panel		
				"	011-014	Leaf 3		
			x	Ficus	015	Spectralon panel		
				"	016-019	Leaf 1		
			x	"	020	Spectralon panel		
				"	021-024	Leaf 2		
			x	"	025	Spectralon panel		
				"	026-029	Leaf 3		
			x	Yucca	030	Spectralon panel		
				"	031-034	Leaf 1		
			x	"	035	Spectralon panel		
				"	036-039	Leaf 2		
			x	"	040	Spectralon panel		
				"	041-044	Leaf 3		

[0] Clear Sky; [1] Haze; [2] Thin cirrus - sun not obscured; [3] Thin cirrus - sun obscured; [4] Scattered cumulus - sun not obscured; [5] Cumulus over most of the sky - sun not obscured; [6] Cumulus - sun obscured; [7] complete cumulus cover; [8] Stratus - sun obscured; [9] Drizzle