Chapter 13. **Vegetation spectroscopy**

Lola Suarez*[1], Natalia Restrepo-Coupe[2], Andreas Hueni[3,4], Laurie A. Chisholm[4]

[1] School of Mathematical and Geospatial Science. RMIT University. Melbourne, Australia
[2] Plant Functional Biology and Climate Change Cluster, University of Technology Sydney, Australia
[3] Remote Sensing Laboratories, Department of Geography. University of Zurich, Switzerland
[4] Institute of Conservation Biology and Environmental Management, School of Earth and Environmental Sciences, University of Wollongong

*Corresponding author:

lola.suarezbarranco@rmit.edu.au

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Abstract

Field spectroscopy involves the study of the interrelationships between the spectral characteristics of objects and their biophysical attributes in the field environment (Bauer et al., 1986; Milton, 1987). When applied to vegetated surfaces, the spectral characteristics are function of the status, composition and structure of the elements measured. There are more elements that add undesired effects to the overall signal as the soil background or the viewing and illumination geometry. Like every other measurement in the field, it is very important to be familiar with the instrument used and conscious of good practices that ensure the acquisition of reliable measurements. Moreover, for the comprehensive use of the data in future studies, it is very important to document the measurement protocol and a proper collection of measurement auxiliary data. This chapter compiles some basic theory about photon-vegetation interaction and some guidelines for field spectroscopy measurement.

Key points

- Vegetation spectral response is function of leaf composition, age and phenology, plant architecture, illumination intensity and illumination/viewing angles.
- The key recommendations to follow when measuring in the field are: ensure constant illumination, avoid shadows or external elements within the instrument footprint and be sure the instrument and calibration panels are calibrated and in good state.
- There are different measurement set-ups and sampling designs (11.2.2 and 11.2.3), the operator must choose one and document it as part of the metadata of the measurement.
- It is very important to properly document the measurements with enough metadata allowing future users to understand how the data was taken (see 11.2.4 for metadata collection).

13.1 Vegetation spectral response

When an incident radiation ($W \cdot sr^{-1}$) reaches a surface, it is reflected, absorbed or transmitted. The sum of these three processes accounts then for the total of the incoming energy, being expressed most of the times in proportional units and their sum being equal to 1. Little of the incident visible (0.4–0.7 mm) or near-infrared (0.7–1.3 mm) energy is reflected directly from the outer surface of a leaf because the cuticular wax layer is nearly transparent to radiation at these wavelengths (Knipling, 1970). Hence, leaf reflectance is low in the visible, starting with very low values in the blue (0.4–0.5 mm), slightly higher in the green (0.5–0.6 mm), and again reaching a minimum in the red (0.6–0.7 mm) (Jackson, 1986) (Figure 13.1). The main responsible of the leaf low reflectance in the visible part of the electromagnetic spectrum is the leaf pigment pool (chlorophyll, carotens and xanthophylls). However, the influence of pigment composition does not affect the near-infrared region significantly (Gates and Tantraporn, 1952). Chlorophyll is mainly absorbing in the red visible portion of the spectrum and partially contributes to the absorption in the blue and the green together with other pigments as carotenes and xanthophylls (Jackson, 1986). In the near-infrared region, leaf absorption/reflection is mainly dependent on the leaf cell structural discontinuities; meanwhile, in the mid-infrared region (1.3–3 mm), water and other compound concentrations play a major role (Peñuelas and Filella, 1998).

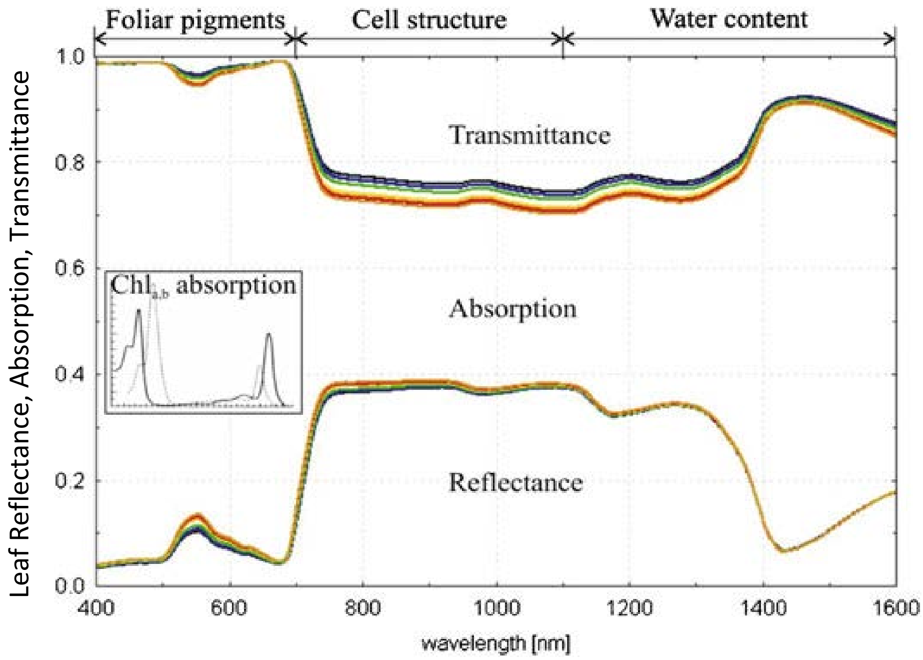


Figure 13.1 Reflectance, transmittance, and absorption of a leaf, the chlorophyll a and b absorption in the visible, and the regions affected by foliar pigments, cell structure, and water content.

Figure 13.1 depicts the reflectance, transmittance, and absorption proportional values of a leaf specifying the spectral regions affected by pigment absorption, cell structure, and water content. The chlorophyll absorption spectrum is also presented with two characteristic peaks, in the blue and red regions.

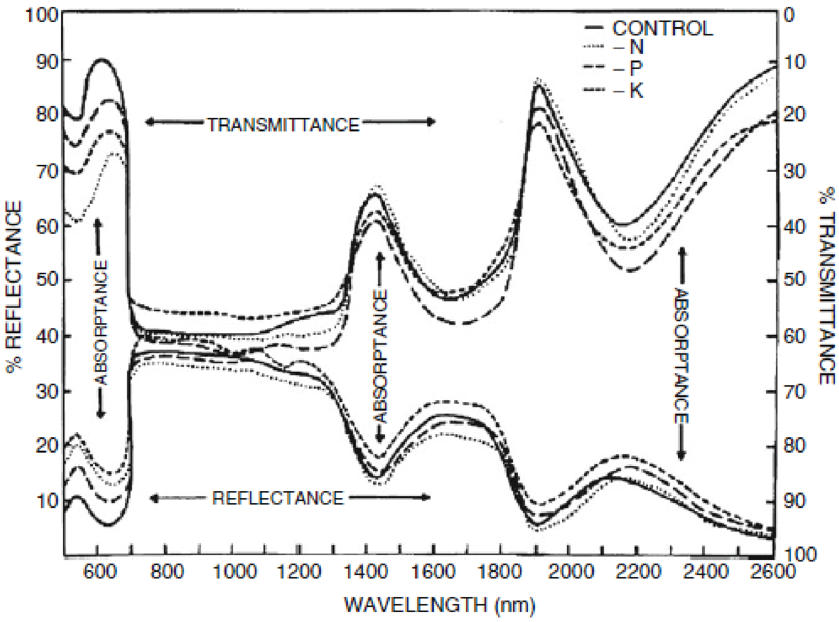


Figure 13.2 Reflectance and transmittance leaf spectra corresponding to healthy, nitrogen-, phosphorous-, and potassium-deficient leaves (Adapted from Al-Abbas et al., 1974).

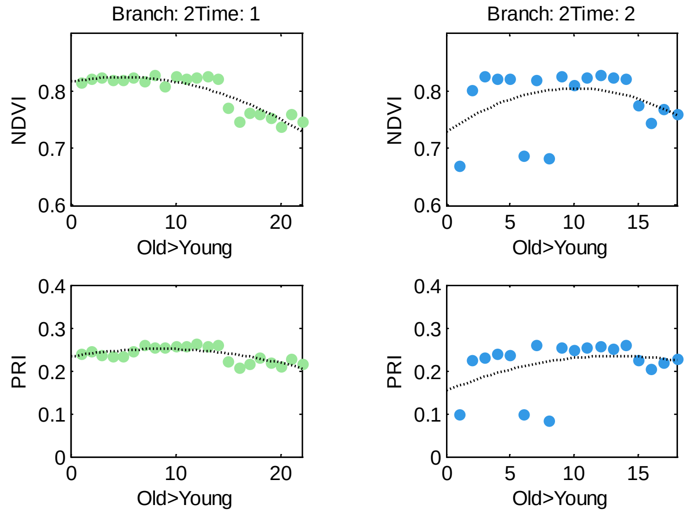
The leaf spectrum is affected by several factors including leaf age, phenology, and a highly variable range of stressors, for example, nutrient and water deficiencies, and insects and other damaging agents. Figure 13.2 presents the differences in the reflectance and transmittance spectra of a healthy leaf and the spectra of leaves compared to those with nitrogen, phosphorous, and potassium deficiencies. As the impact of different nutrients in the electromagnetic spectrum generally overlaps, it is important to identify spectral regions where differences are driven by individual nutrients for a proper pathology assessment.

Periodic changes on meteorological drivers as precipitation, solar radiation and temperature, among others, influence different biological events (e.g. flowering, fruiting, etc.). These seasonal cycles and their relationship with biotic and physical drivers is known as phenology (see Phenology Validation section for definitions). At the leaf level, phenology is characterized by changes in photosynthetic capacity, spectral properties, and leaf chemistry. The phenology of temperate broadleaf and tropical deciduous species is generally straight forward with a clear and visible annual cycle that starts with springtime leaf-flux to autumn abscission at temperate areas and it is driven by the onset of the rainy and dry periods at tropical sites (e.g. leaf longevity of tropical deciduous is 6 to 9 months (Sobrado, 1994)). For eight savanna tree species, Eamus et al. (1999) showed a drop in assimilation rates (µmol m-2 s-1), foliar N content (mg g-1) and Specific Leaf Area (SLA, cm2 g-1) in June – Sep. If we assume that the phenology of the leaf spectral properties is a reflection of leaf chemistry (e.g. chlorophyll content and anthocyanin) and leaf traits (e.g. SLA), we should expect that reflectance, absorbance and the different vegetation indices (e.g. Enhanced Vegetation Index (EVI) and Photochemical Reflectance Index (PRI)) will also change. Patterns of shoot extension and refoliation of eucalypts differ from many of the commercially-important tree genera in the temperate Northern Hemisphere. Eucalypts have a very opportunistic leafing phenology, although rapid leaf expansion usually occurs in moderately synchronised seasonal flushes (Stone etal 2005). If we want to understand the phenology of leaf optical properties, it is required to follow a set sample of leaves through time. Figure 13.3 shows seasonal changes (occurred on a period of 3-months) in optical properties and the effect of leaf age on the spectra. Changes in reflectance and transmittance will be species specific, will have a different effect at the top-of-the-canopy and shaded leaves and in many cases they will be site specific, thus all this factors should be balanced when planning a field campaign and the design should be based on the objectives of the project (e.g. validation of satellite products, chemistry models, etc.). Optical measurements on a seasonal basis offer promise for future studies and are appropriate given sufficient resources.

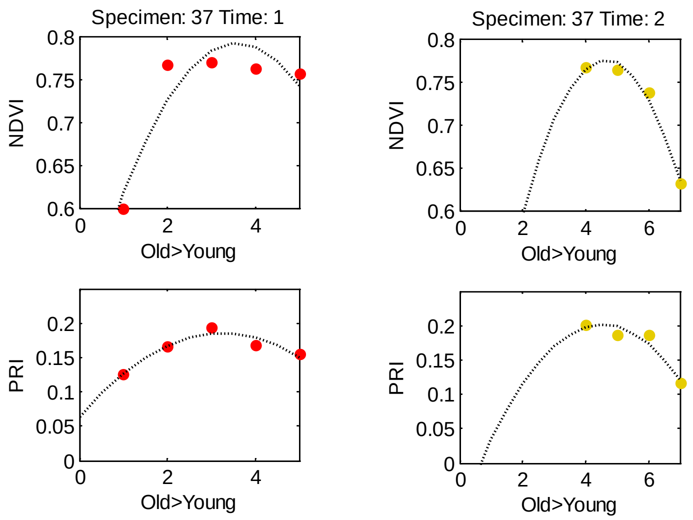
Plant canopies are structurally diverse due to unique spatial patterns that different species adopt for intercepting light and even regulating the light (Atwell et al 1999). Thus, at canopy level, the interaction of radiation within the vegetation depends on the contribution of several components such as leaves, stems, soil background, illumination and view properties of each canopy element as well as on their number, area, orientation and location in space (Goel and Thompson, 2000; Koetz *et al.*, 2004).

In addition, the illumination and viewing geometry play a very important role in the resulting reflectance (Curtiss and Goetz, 1999; Perbandt et al., 2010). The changes in the overall reflectance as function of the illumination geometry are defined in the Bidirectional Reflectance Distribution Function (BRDF) for each viewing angle. The BRDF of a particular canopy is dependent of the amount and disposition of the canopy elements, being highly affected by the total leaf area, foliage clumpiness and the leaf angle distribution.

As a consequence, indices or algorithms derived from leaf measurements are not applicable to canopy measurements. Some authors have overcome this problem by combining indices (Haboudane et al., 2002) and some others have drawn upon model simulations of such effects (Cescatti, 1997; Combal et al., 2002; Suarez et al., 2009).



Tropical plant (*Ficus sp.)*



Broccoli (*Brassica oleracea*)

Figure 13.3 Relationships between relative leaf age (old to young along a branch), Normalized Vegetation Index NDVI (top panels) and the Photochemical Reflectance Index, PRI (lower panels). Leaf spectra obtained using an ASD portable spectroradiometer and a LI-1800 integrating sphere. Each point correspond to the mean of 6 measurements (each a 30 sample average) (a) initial (t1) NDVI (b) 3-months after (t2=t1+3months) NDVI Tropical plant, (c) initial (t1) PRI (d) 3-months after (t2=t1+3months) PRI Tropical plant. (e) initial (t1) NDVI (f) 3-months after (t2=t1+3months) NDVI agricultural plant, (g) initial (t1) PRI (h) 3-months after (t2=t1+3months) PRI agricultural plant.

13.2 Field spectroscopy measurement

There are a number of good practices or recommendations for the acquisition of spectral measurements in the field:

- Illumination conditions must be constant during the whole measurement (clear sky conditions, avoid cloud cover changes).
- The measured surface should not be shadowed by the operator or measuring structures. The operator should stand perpendicular to the solar plane, not shadowing the target and not being in the hotspot position to avoid possible backscattering on the target.
- The carrier (person or structure) cannot cover any area within the instrument footprint (see Figure 13.5 a). In the case of being in the proximity, the person should dress in low-reflective clothes; structures should not be of highly reflective materials (see http://discover.asdi.com/Portals/45853/docs/Measurements-paper-10-26-12.pdf for more information).
- Fibre optics must be handled with care. They are composed of a high number of individual fibres that are broken easily when folded. In case of rupture of part of the fibres, the instrument has to be recalibrated.
- Assure the instruments and reference panels have been calibrated.

13.2.1 Target selection

If the spectroscopy measurements are meant to be related to airborne/satellite imagery, targets should cover at least 3x3 pixels square to ensure a minimum of 1 pure image pixel. Spectrometer should capture only the target when performing the instrument calibration or data collection (see section 13.2.3.). In order to avoid unwanted BRDF effects on the measurements, targets should be as flat and levelled as possible. In the case of being selected for calibration purposes, the targets and the surrounding should be homogeneous in illumination and in the property needed to be validated. Areas that are half-shadowed or that have an adjacent element should be avoided because such elements can affect the measured spectra.

13.2.2 Spectral measurement set up

Leaf measurements

Leaf hemispherical reflectance and transmittance can be measured using an integrating sphere attached to a spectrometer. The resulting spectral characteristics will depend of the spectrometer used. The integrating sphere is used to create a perfectly diffuse illumination on the leaf and to record the hemispherical reflectance and transmittance (Figure 13.4. b).

For leaf directional reflectance measurements, a leaf clip can be used. Leaf clips can either have their own light source (e.g. ASD leaf clip; Figure 13.4 a) or use natural light, as for chlorophyll fluorescence measurements (Rascher et al., 2011). Leaf clips are including a reference material allowing the measurement of reflectance and radiance in case the attached spectrometer is calibrated for radiance measurements. For more information about illumination-viewing geometries in spectroscopy measurements, please refer to Schaepman-Strub et al. (2006).

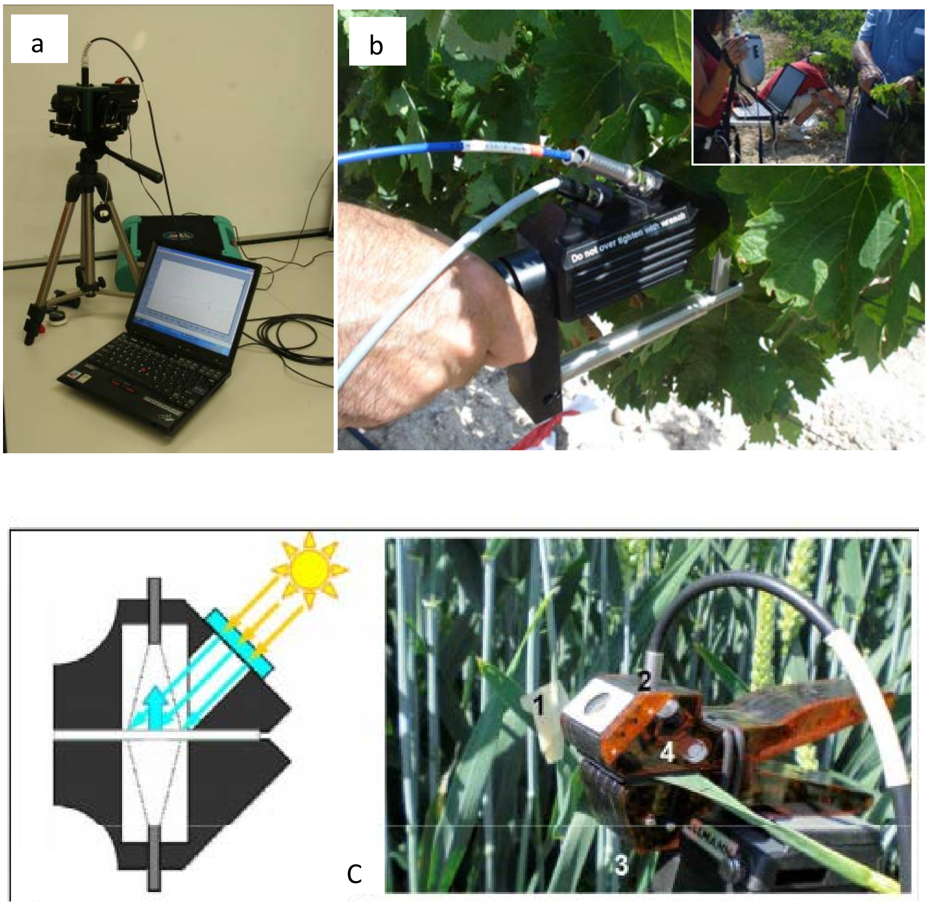


Figure 13.4 (a) Measurement set-up for leaf hemispherical reflectance and transmittance spectroscopy using an integrating sphere attached to a field spectrometer. (b) Leaf biconical reflectance measured in the field with a leaf probe attached to a field spectrometer. (c) Leaf probe to measure using natural illumination (from Rascher et al., 2011).

Canopy measurements

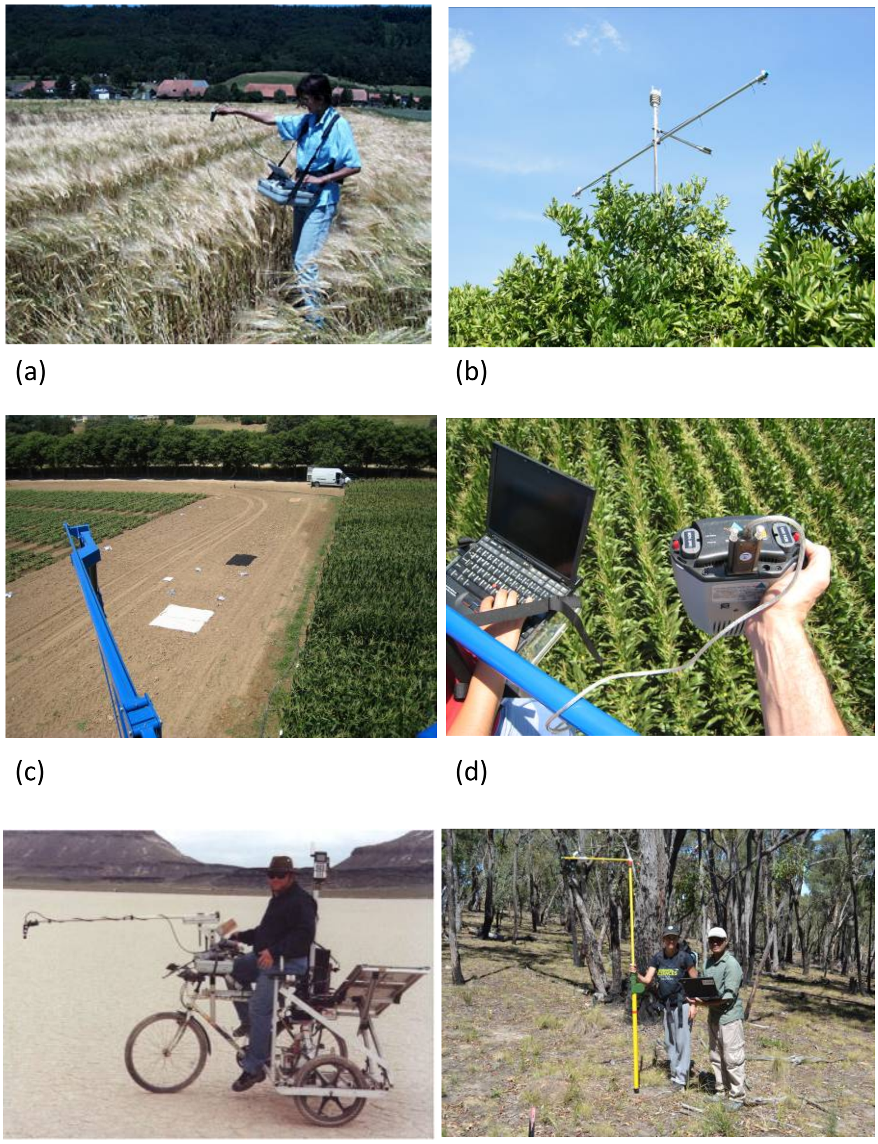


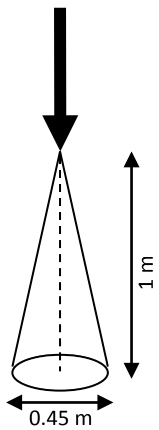
Figure 13.5 (a) Direct walking transect measurements, (b) use of field measuring structures on tree crowns where the bare fibre is attached to the structure pointing at nadir on the same point. For the measurement, the loose end of the fibre is attached to a field spectrometer. Portable measuring structures: (c and d) using a cherry picker (Quantalab, Spain; Berni et al., 2009); (e) telescopic pole attached to a motorbike (NASA JPL 'Reflectomobile', Thome et al., 1994); and (f) a pole is used to reach to measure at a certain height without interfering the instrument footprint (RMIT University, Australia).

- **Direct measurements:** Direct measurements can be taken by pointing the fibre (using fore optics or not) on the canopy.
- **Fix measuring structures:** Bare fibres can be installed on fix measuring structures to get continuous measurements (installing the spectrometer in the field) or for punctual measurements by attaching a spectrometer to the fibre end. These structures could be used for individual crown monitoring or ecosystem biophysical parameters, now common in many eddy covariance sites (see Balzarolo et al. 2011)
- **Portable measuring structures:** Portable structures can be used for measurements at different heights. They include portable poles with a fibre attached to measure at a height up to 5-7 metres or portable platforms (up to 15 m, e.g. cherry picker). In both cases it is important to always be

aware of the instrument footprint on the canopy and avoid the intrusion of the structure on such footprint.

13.2.3 Sampling designs

It is important to bear in mind the instrument footprint on the canopy. The theoretical footprint is function of the instrument field of view (FOV), orientation and the measuring height. The manufacturers provide a nominal solid included angular value per foreoptic but the methods used to determine this FOV parameter are not specified, and associated uncertainties are not made explicit (MacArthur et al., 2012). Figure 13.6 presents the equivalent footprint diameter corresponding to typical nominal field of view angles used in field spectroscopy measurements at nadir. When we are measuring a certain point on a surface we should be sure the footprint area belongs 100% to the target. Besides, it has been demonstrated that the real instrument FOV is irregular and most of the times exceeds the limits of the theoretical FOV (MacArthur et al., 2012). This fact should be taken into account considering an instrument footprint larger than the nominal when taking spectral measurements. The nominal footprint diameter (*d*) can be calculated as [1] for nadir measurements with a α FOV and as [2] for measurements taken with a FOV α at a viewing angle β.

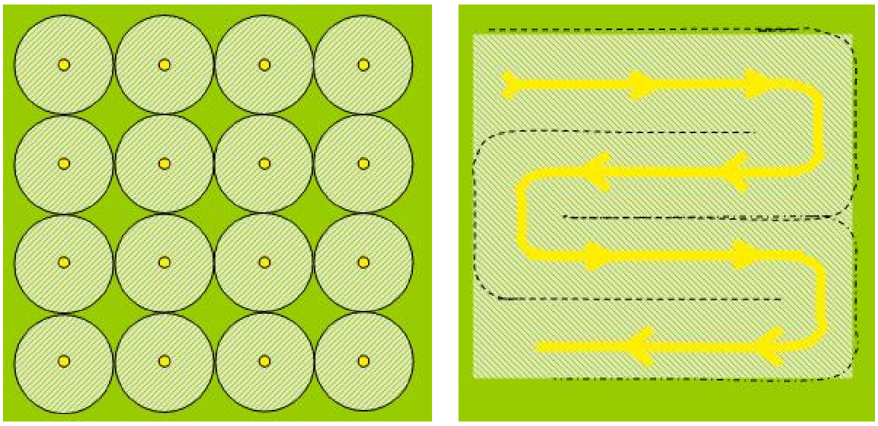


	Viewing angle (FOV)	Footprint diameter measuring at 1 m height
Bare fibre	25 deg	45 cm
Fore optics	10 deg	17.4 cm
	1 deg	1.74 cm

Figure 13.6 Left panel: Schema of the nominal footprint of an instrument measuring through a bare fibre at a 1 m distance. Right panel: Indicative nominal diameter of the footprint measuring at 1 m height with different viewing settings (bare fibre and 10 and 1 degrees foreoptics).

$$d = 2 * height * \tan(\alpha / 2) \quad \text{(equation 13.1)}$$

$$d = 2 * height * [\tan(\alpha / 2) - \tan(\beta)] \quad \text{(equation 13.2)}$$



(a) (b)

Figure 1.7 Common sampling schemes used to get representative spectroscopy measurements of an area.
(a) Based on individual points at an approximate distance of the theoretical footprint diameter.
(b) Taking continuous measurements while walking over the sample surface.

In order to take a representative measurement of an object, several readings should be taken covering the whole object area. This can be done by taking punctual readings all over the target or by taking continuous measurements while walking pointing at the target (Figure 13.7). In both cases, it is important to maintain the right position with respect to the sun and if possible to walk on the surface area that has been already measured.

13.2.4 Metadata collection

In order to facilitate the long-term use of the spectral data, pertinent metadata has to be collected. There is a general set of metadata that should be collected for every spectral measurement.

General metadata includes:

- Date and location
- Sky conditions in case the sky is not completely clear
- Instrument and reference panel REF numbers (the one of the instrument is available in the header of the resulting file)
- Foreoptics used (This may be recorded by the instrument as well if set correctly)
- Additional comments

The measurements for specific experiments need additional metadata documenting relevant information of the target. In the case of measuring leaf or canopy spectra, the specific metadata includes:

- Scale (leaf or canopy)
- Species
- Other measurements taken (e.g. pigment content, specific leaf area, dry matter content, photosynthetic rate, conductance)
- Comments

In the case of measuring the canopy or leaves representing a tree, additional metadata includes:

- Height

- Diameter at breast height (DBH)
- Position of the crown relative to surrounding vegetation (emergent, isolated, part of the canopy)
- Approximate percentage cover
- Approximate crown diameter
- Extra comments (e.g. fork trees, specific existing damage, bended trunk, high decolouration etc.).

13.2.5 Data storage

Optimally, the spectral measurements and associated metadata should be stored within a spectral information system, such as SPECCHIO(V3). Essentially, at this stage the spectral data enters the lifecycle stages of data ingestion, metadata augmentation, information building and information retrieval. For details on the spectral information system based spectroscopy data lifecycle please refer to Chapter 14.

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Acronyms

BRDF	Bi-directional reflectance distribution function
DBH	Diameter at breast height
EVI	Enhanced vegetation index
FOV	Field of view
NDVI	Normalised difference vegetation index
PRI	Photochemical reflectance index
SLA	Specific leaf area