*Sensing a Changing World* **2012**

# A new setup to measure bidirectional reflectance distribution functions

**Peter Roosjen[1,]*, Jan Clevers[1] and Harm Bartholomeus[1]**

[1] Laboratory of Geo-Information Science and Remote Sensing, Wageningen University / P.O. Box 47, 6700 AA Wageningen, The Netherlands; E-Mails: peter.roosjen@wur.nl (Peter Roosjen); jan.clevers@wur.nl (Jan Clevers); harm.bartholomeus@wur.nl (Harm Bartholomeus)

***** Author to whom correspondence should be addressed; E-Mail: peter.roosjen@wur.nl (Peter Roosjen);

**Abstract:** The Plant Facility, a new laboratory goniometer system, built by the Wageningen University has been tested in order to take bidirectional reflectance distribution function (BRDF) measurements. An ASD FieldSpec 3 spectroradiometer mounted on an industrial robot arm is able to measure small targets over the full hemispherical dome. Due to the fast acquisition time it is a promising setup for BRDF measurements of natural targets. In this paper, the preliminary results of BRDF measurements of freshly grown watercress and lawn grass are presented. The results show that both watercress and lawn grass show anisotropic behavior and that LAI plays an important role.

**Keywords:** BRDF, laboratory measurements, goniometer, anisotropy

## 1. Introduction

Research has shown that most natural surfaces show anisotropic (non-Lambertian) behaviour, i.e. the spectral distribution and the intensity of the reflected radiance varies with different illumination and viewing geometries [1, 2]. The bidirectional distribution function (BRDF) as defined by [3] is used to describe the reflectance of a surface as a function of illumination and viewing geometry. On the one hand, information on the BRDF of targets is relevant for normalizing images taken under different illumination and/or viewing conditions [4], but on the other hand multi-angular observations also provide additional information that can be used to improve the accuracy of retrieved products [5, 6]. In order to determine the BRDF, Wageningen University has now built a laboratory goniometer system, known as the “Plant Facility”, for measuring the reflectance anisotropy of soils, leaves and small canopies under controlled solar illumination conditions. The core of the goniometer system is formed by an industrial robot arm, on which an ASD FieldSpec 3 spectroradiometer (Analytical Spectral Devices, Boulder, CO, USA) is mounted. This robotic system is able to take measurements at zenith angles ranging from -90° to +90° with a dome radius which can be varied from 25 cm up to 100 cm.

Advantages of this system compared to others are the theoretically unlimited positions that can be measured and the fast acquisition time: a scan over the whole dome in a resolution of 15° and 30° in zenith and azimuth direction, respectively, takes approximately 10 minutes. A fast acquisition time is of great importance when measuring vegetation targets. The strong irradiance of the laboratory lamp may cause dehydration and wilting of the vegetation and therefore alter the reflected signal [7].

## 2. Experimental Section

### *2.1 Targets*

40 x 40 cm plots freshly grown lawn grass (*Lolium perenne* L.) and watercress (*Nasturtium officinale* R.Br.) served as the objects for the BRDF measurements (figure 1). These targets were chosen for their leaf angle distribution (LAD). Lawn grass has an erectophile LAD and watercress has a planophile LAD. The measurements were taken on plots with 7 and 18 days old lawn grass and watercress. Here is assumed that the leaf area index (LAI) increased when the age of the vegetation increased.

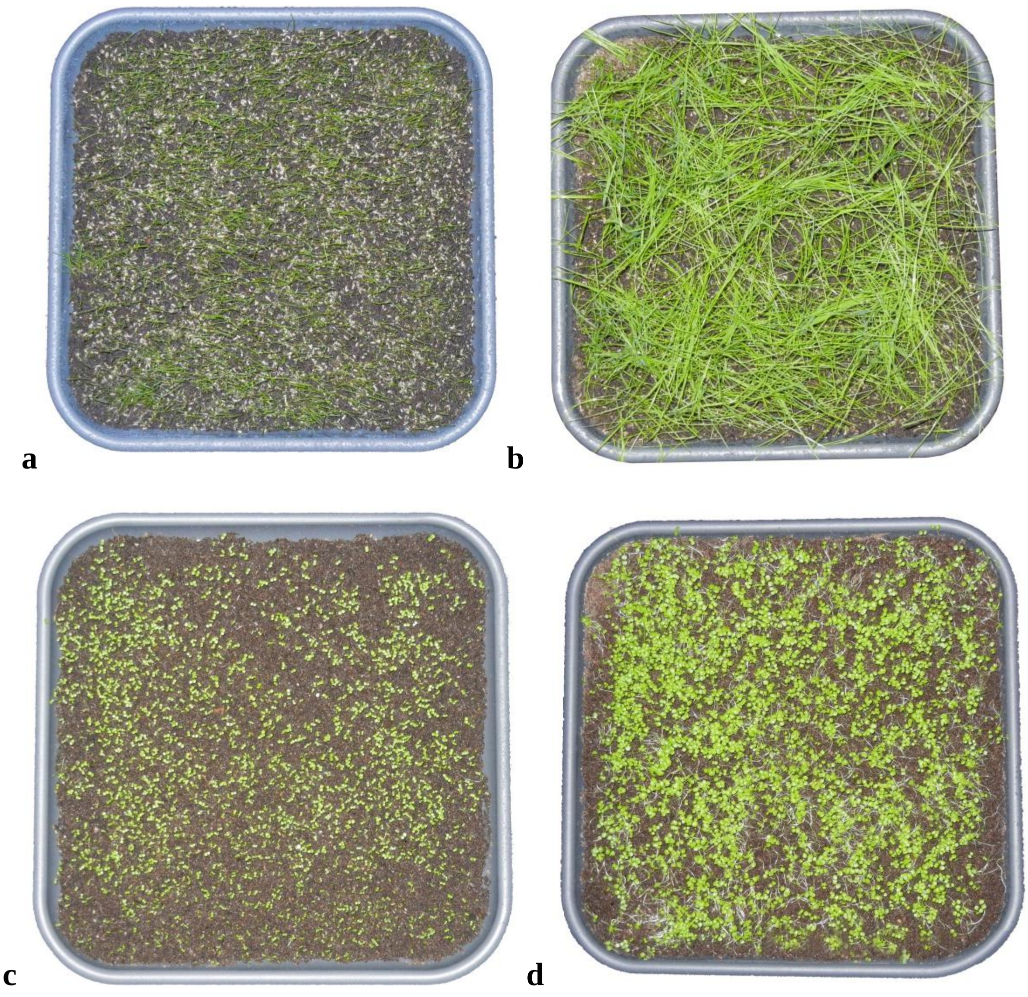
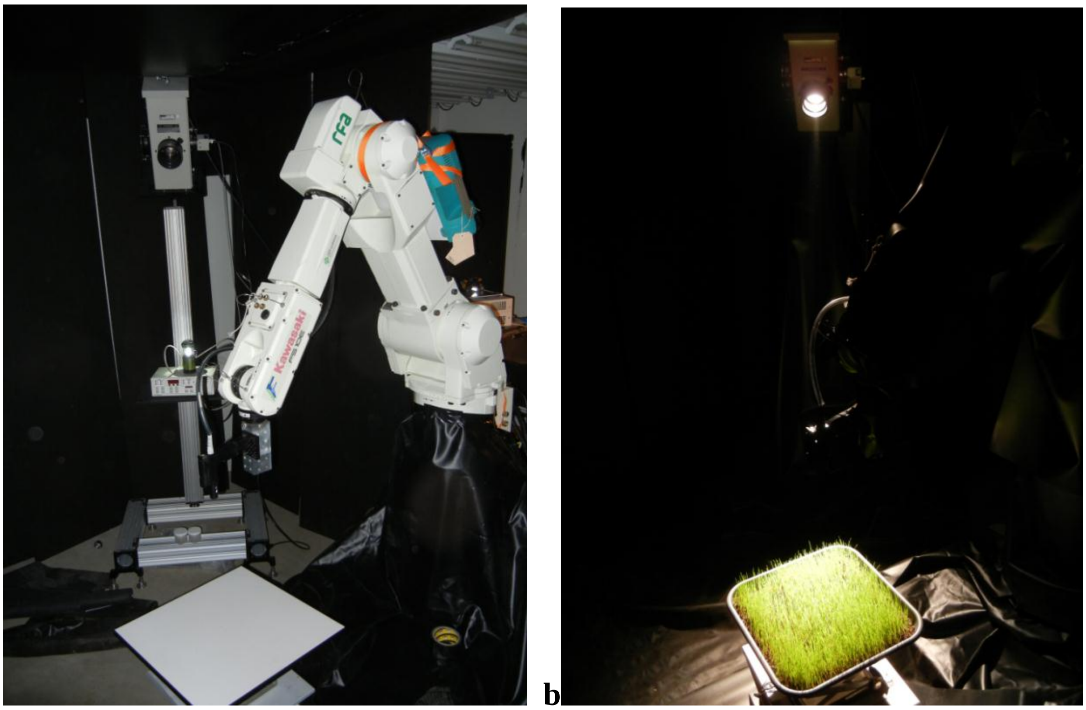



**Figure 1.** (**a**) 7 Days old lawn grass; (**b**) 18 Days old lawn grass; (**c**) 7 days old watercress; (**d**) 18 days old watercress. The images were taken at approximately nadir position.

*2.2 Laboratory setup*

The ASD FieldSpec 3 was mounted on a Kawasaki FS10E industrial robot arm. For the measurements, the sensor – target distance was set at 40 cm. The sensor took measurements ranging from 350-2500 nm with a spectral resolution of 1 nm. The instantaneous field of view (IFOV) of the ASD was set at 8°. As light source, a collimated 1000 Watt Quartz Tungsten Halogen (QTH) lamp was used. To avoid unwanted scattering, the walls of the laboratory were covered with wall panels which were painted with black latex. The robot, the floor and the ceiling were covered with black PVC foil (figure 2). Both the latex and the foil have a reflection of less than 3% in the visible and NIR.

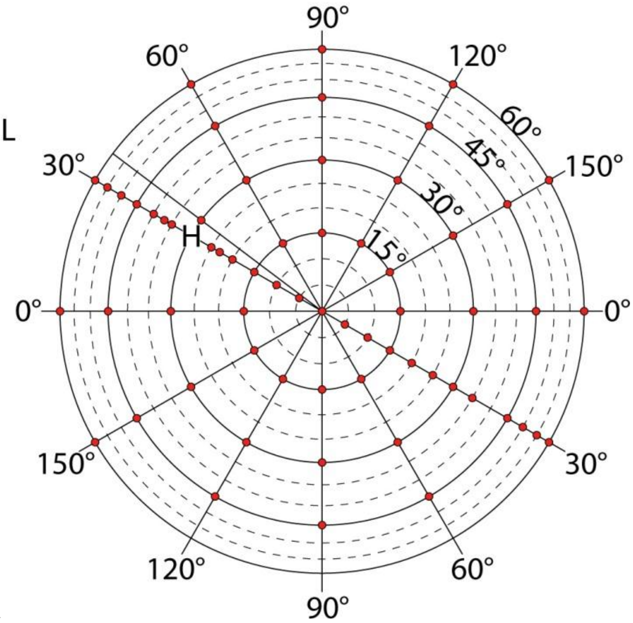


**a** **b**

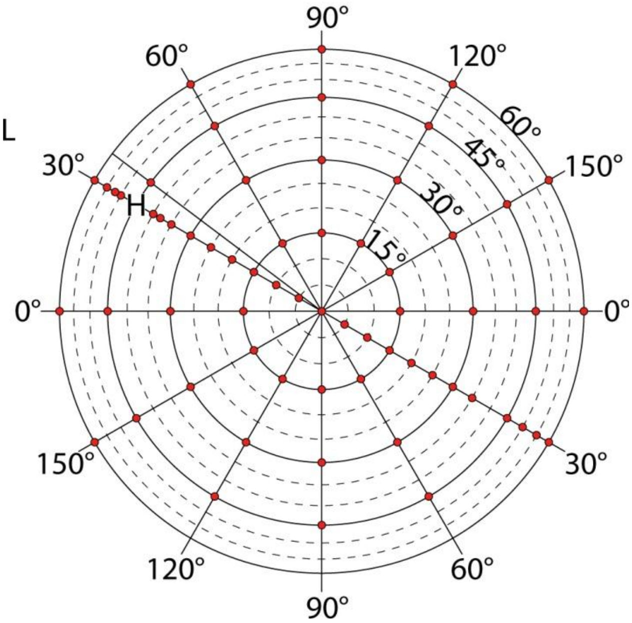
**Figure 2.** (**a**) Construction of the laboratory setup; (**b**) Laboratory setup during the measurements

*2.3 Measurements*

Measurements on the lawn grass and watercress were taken at an illumination zenith angle of both 30° and 45° to determine the effect of different illumination positions. The targets were measured in a resolution of 15° and 30° over the full azimuthal plane with zenith angles from -60° to +60°. Each scan started and ended with a series of measurements over the principal plane with a zenith angle resolution of 5°. Around the hotspot additional measurements were taken. Per scan, 96 measurements were taken at 63 different positions (figure 3). Before and after each scan, a Spectralon panel was measured to determine if the sensor was stable during the scans.




**a**




**b**

**Figure 3.** (**a**) Measurement positions with an illumination zenith angle of 30°; (**b**) Measurement positions with an illumination zenith angle of 45°. L is the position of the light source and H is the hotspot.

At an illumination zenith angle of 30°, 15 measurement positions were left out of the analysis due to shadows on the targets caused by the robot arm.

## 3. Preliminary results and discussion

Figure 4 displays an interpolated polar plot of the bidirectional reflectance factor (BRF) of 18 days old lawn grass under an illumination angle of 45°. Clearly visible is the hotspot effect in the backscatter direction. This happens due to the erectophile LAD which causes irradiance to be reflected back in the direction of the light source. This backscatter effect is absent when looking at the reflectance of 7 days old lawn grass (figure 5). Here it seems the reflectance increases when the zenith viewing angle increases, independently of the azimuth viewing angle. At nadir position, there is a great influence of the soil because the lawn grass is not fully covering the surface (figure 1a). When the viewing angle increases, the amount of visible soil decreases and the amount of lawn grass measured by the sensor increases. Because the 7 days old lawn grass is very thin and slightly transparent there is no clear shadow effect and therefore no hotspot. For both the young and the old lawn grass the effects are wavelength independent.

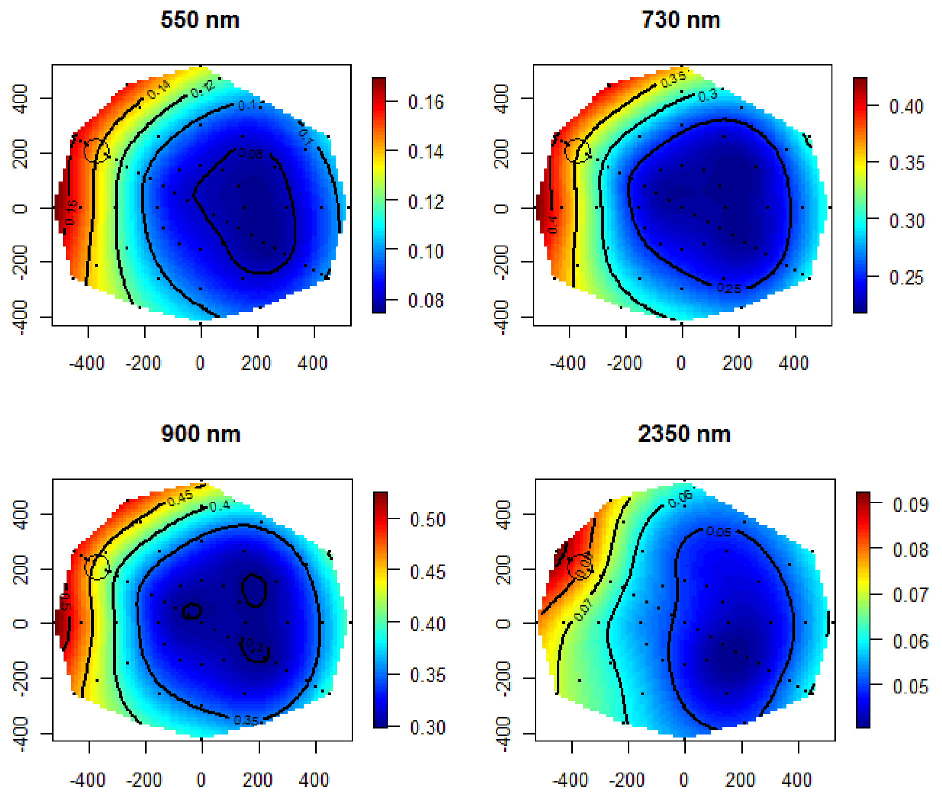



**Figure 4.** Polar plot of BRF values observed over a target with a 18 days old lawn grass at 550 nm, 730 nm, 900 nm and 2350 nm ($\theta_i = 45°$). The circle denotes the hot spot position.

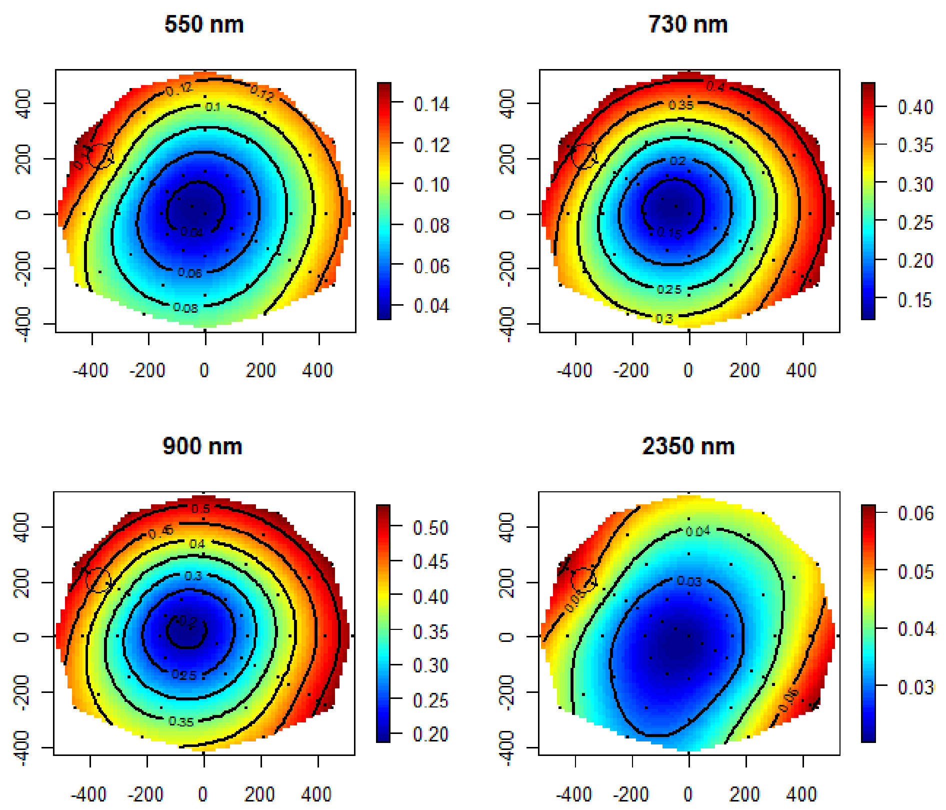



**Figure 5.** Polar plot of BRF values observed over a target with a 7 days old lawn grass at 550nm, 730nm, 900nm and 2350nm ($\theta_i = 45°$). The circle denotes the hot spot position.

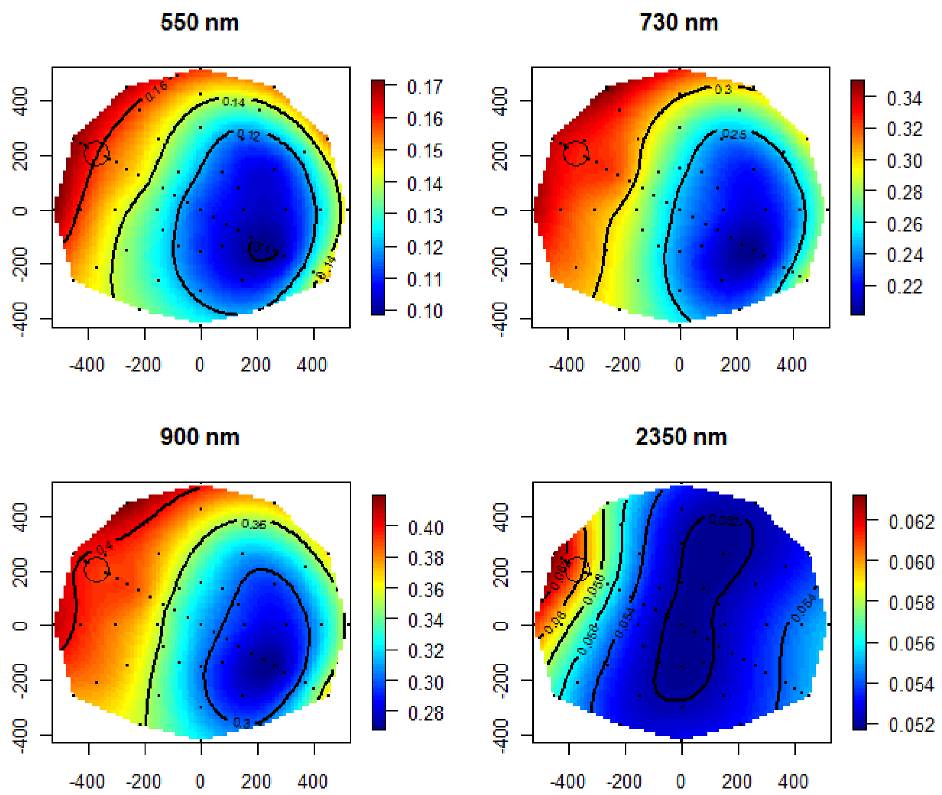



**Figure 6.** Polar plot of BRF values observed over a target with a 18 days old watercress at 550nm, 730nm, 900nm and 2350nm ($\theta_i$ = 45°). The circle denotes the hot spot position.

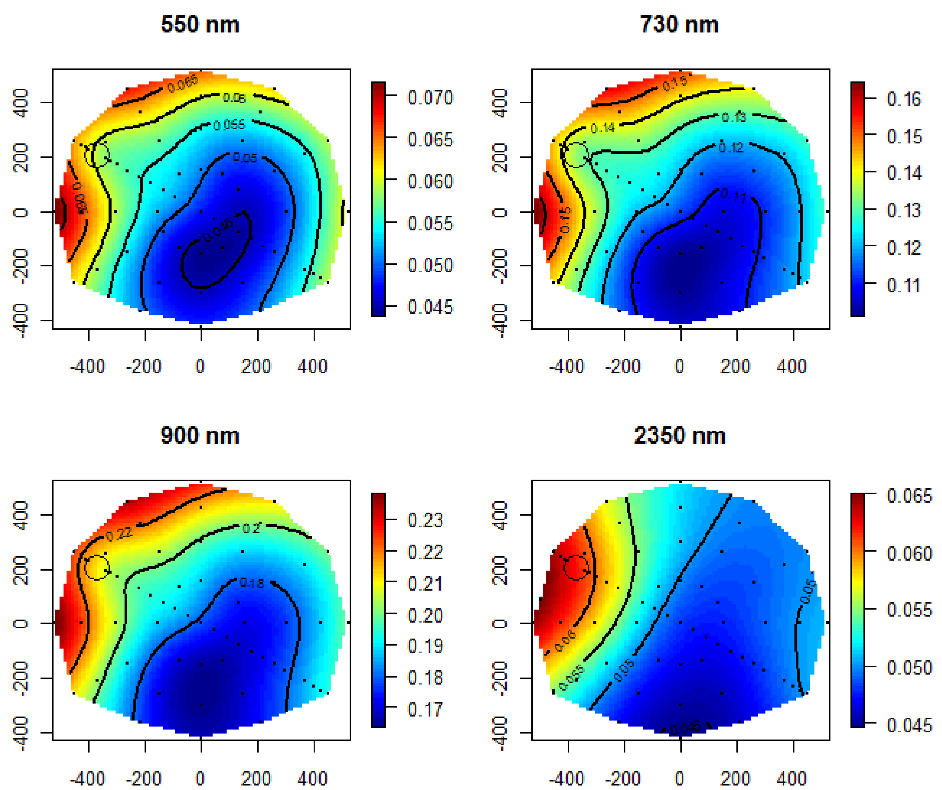



**Figure 7.** Polar plot of BRF values observed over a target with a 7 days old watercress at 550nm, 730nm, 900nm and 2350nm ($\theta_i$ = 45°). The circle denotes the hot spot position.

Both the 7 and the 18 days old watercress shows a hotspot in the backscatter direction and a cold spot in the forward scatter direction (figure 6 and 7). Besides the hotspot effect, watercress shows an increase of the reflected signal when the viewing zenith angle increases. The same applies when looking at the lawn grass because both the young and old watercress do not fully cover the surface (figure 1c and 2d): with an increasing viewing zenith angle the amount of leaves that are measured also increases and the amount of soil that is measured decreases. The reflected signal increases because the watercress has a higher reflectance in the green (550 nm), the red edge (730 nm) and the NIR (900 nm) compared to the bare soil on which the watercress was grown (figure 8).

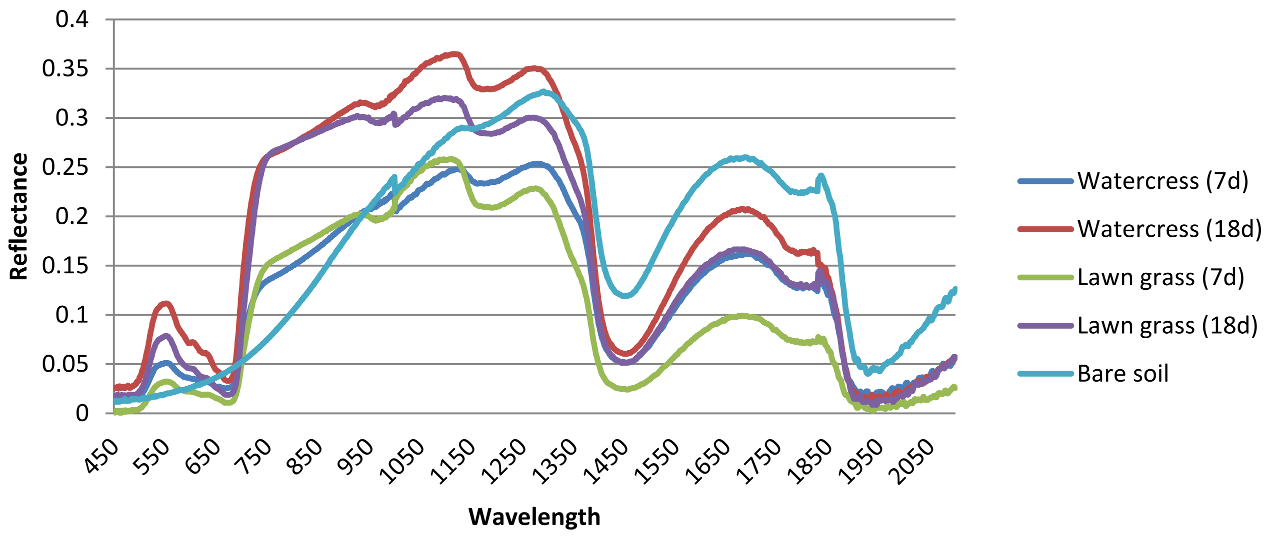



**Figure 8.** Spectral signatures acquired at nadir position of watercress (7 and 18 days old) and lawn grass (7 and 18 days old). The bare soil is the soil on which the watercress and lawn grass were grown.

During the acquisition of the measurements over the full dome, the robot was programmed to measure the nadir position four times in order to determine if the reflected signal has changed due to vegetation stress caused the irradiance of the light source. Between these measurements there was a time interval of approximately 4 minutes. The results of these measurements are shown in figure 9.

There are no clear differences between the repetitive measurements at nadir position. Therefore it can be assumed that within the short acquisition time of the measurements there are no signs of dehydration and wilting of the vegetation. Knowing that the vegetation has not changed during a scan of the full hemispherical dome makes it possible to compare all the different measurement positions.

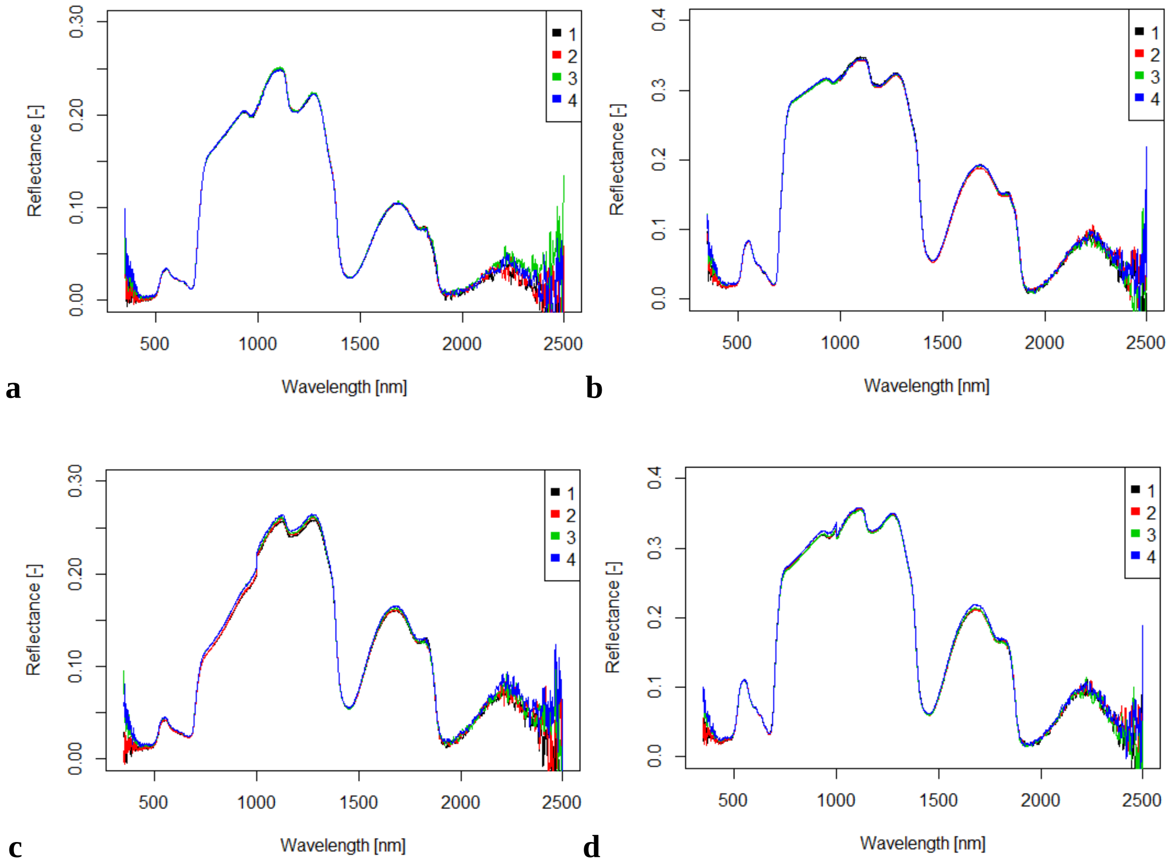



**Figure 9.** Repetitive measurements at nadir position of (**a**) 7 Days old lawn grass; (**b**) 18 Days old lawn grass; (**c**) 7 days old watercress; (**d**) 18 days old watercress. Measurement 1 was taken at the beginning of the measurements and measurement 4 at the end. Measurements 2 and 3 were taken in the middle.

## 4. Conclusions and Outlook

In this paper the first results of BRDF measurements at the Plant Facility in Wageningen are presented. The results show that both lawn grass and watercress show anisotropic behavior. 18 Days old lawn grass and 7 and 18 days old watercress show a clear hotspot which appears to be wavelength independent. For both the watercress and the lawn grass it appears that the amount of leaves that are measured by the sensor have a great influence on the reflected signal. For the green, the red edge and the NIR, if the zenith viewing angle increases and thus the amount of leaves which are measured increases, the reflected signal also increases. This occurs both in the forward and backward scattering direction.

The ASD FieldSpec 3 spectroradiometer mounted on an industrial robotic arm makes it possible to measure small targets over the full hemispherical dome in a short amount of time and is therefore a suitable setup to measure the BRDF of natural objects. The results so far are promising for future BRDF research. In order to better understand the measured BRDF measurements, relations of this BRDF with LAI and chlorophyll content within vegetation targets have to be studied further.

## References and Notes

1. Kriebel, K.T. Measured spectral bidirectional reflection properties of four vegetated surfaces. *Applied Optics*, **1978**, 17(2), 253-259.
2. Middleton, E.M., D.W. Deering, and S.P. Ahmad. *S*urface anisotropy and hemispheric reflectance for a semiarid ecosystem. *Remote Sensing of Environment*, **1987**, 23(2), 193-212.
3. Nicodemus, F.E., et al., *Geometrical considerations and nomenclature for reflectance.* Natl Bur Stand (US), NBS Monograph, **1977**, 160 pp.
4. Bacour, C., F.M. Bréon, and F. Maignan. Normalization of the directional effects in NOAA-AVHRR reflectance measurements for an improved monitoring of vegetation cycles. *Remote Sensing of Environment*, **2006**, 102(3-4), 402-413.
5. Laurent, V.C.E., et al. Inversion of a coupled canopy-atmosphere model using multi-angular top-of-atmosphere radiance data: A forest case study. *Remote Sensing of Environment*, **2011**, 115(10), 2603-2612.
6. Diner, D.J., et al. New Directions in Earth Observing: Scientific Applications of Multiangle Remote Sensing. *Bulletin of the American Meteorological Society*, **1999**, 80(11), 2209-2228.
7. Sandmeier, S., et al. Sensitivity analysis and quality assessment of laboratory BRDF data. *Remote Sensing of Environment*, **1998**, 64(2), 176-191.