The emission spectra of lamps in the Botanical Gardens of Utrecht University

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Introduction

In the botanical garden of Utrecht University (UU) various types of lamps are used to stimulate plant growth. The spectral emission of the lamps should ideally match the spectrum of the sun i.e. 400 – 2500nm. The emission spectrum of the sun is shown in figure 1. The sun mainly emits electro-magnetic energy in Visible Wavelengths (VIS) 400 to 700 nm, Near Infrared (NIR) 700 to 1100nm and Short Wave Infared (SWIR) 1100 to 2500nm. Most lamps do not cover the entire solar spectrum so, next best are lamps that emit in the the spectral region of plant photosynthetic activity. This spectral region of plant photosynthetic activity generally covers the visible wavelengths between 400 and 700 nm (vander Meer & De Jong, 2004). In this region the different pigments in the leaves have specific radiance (light) absorptions peaks mainly in the blue and red visible wavelengths as illustrated in figure 2. A laboratory study was carried out aiming at determining the spectral emission of six sets of lamps available in the UU botanical garden. This report describes the equipment used and the experimental setup followed by the results.

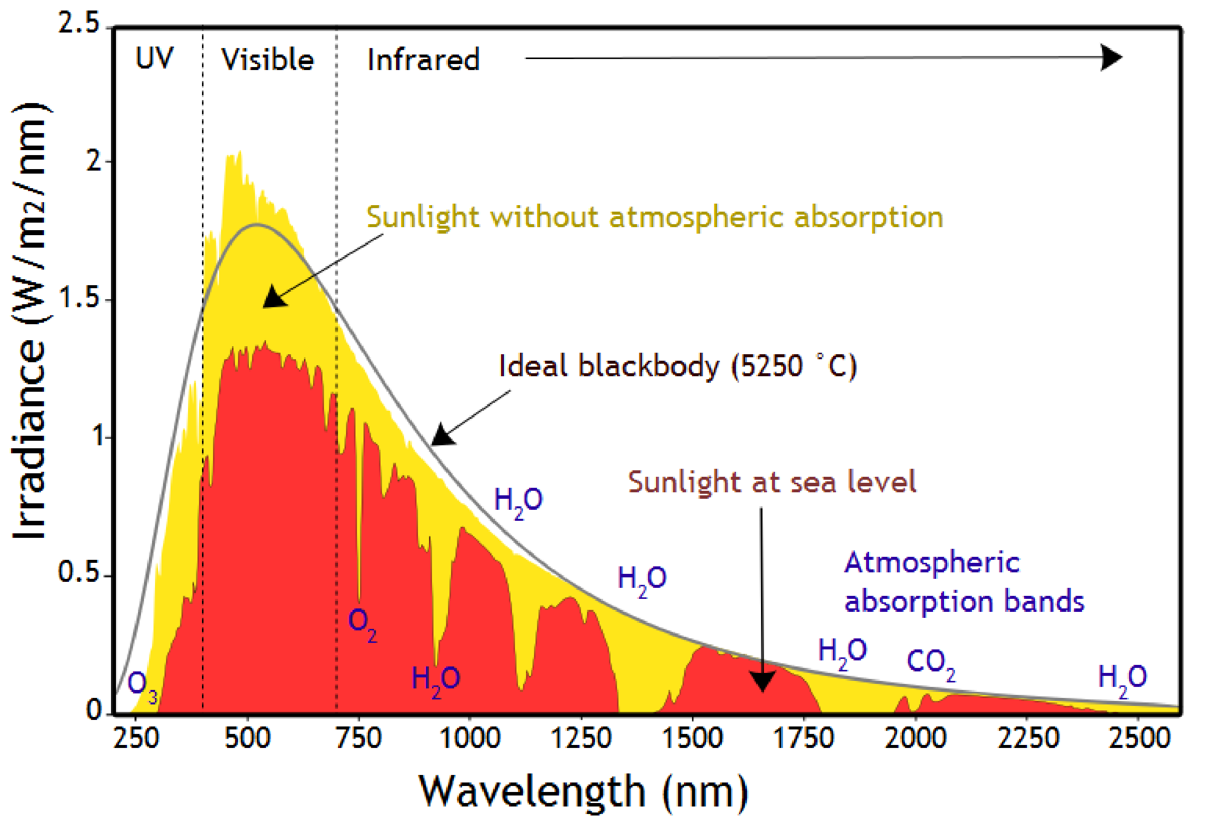


Figure 1: The emission spectrum of the sun. The blackline shows the emission of an ideal blackbody according to the law of Stefan-Boltman and the displacement law of Wien. In yellow and red the solar spectrum is shown as measured at the top of the atmosphere or at sea level respectively. In blue the major gas and water vapor absorption bands are indicated. Visible light ranges from 400 to 700nm. Souce: wikipedia/Sunlight.

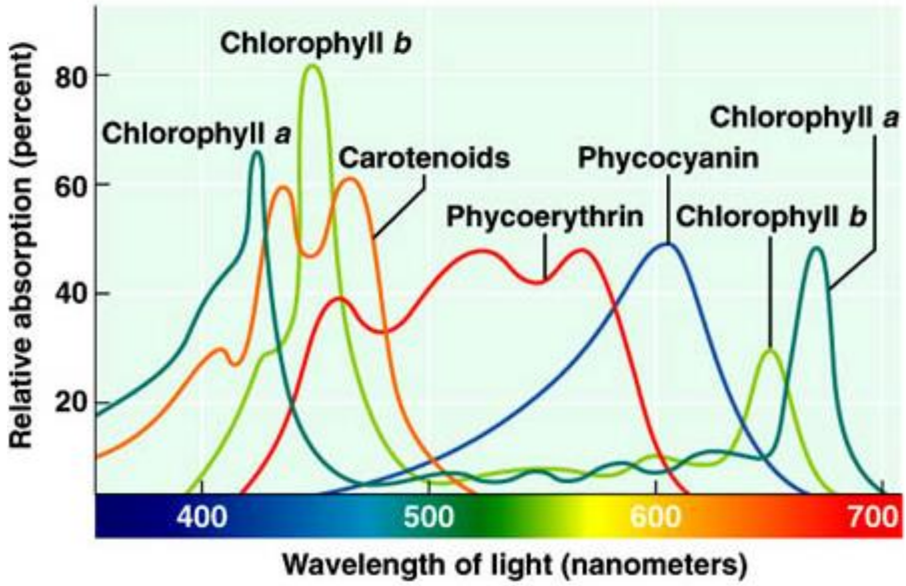


Figure 2: Light absorption maxima of pigments in the leaves of plants in the visible wavelengths. Note that this figure shows only a part of the solar spectrum in figure 1. Source: McGraw-Hill Pub.

Methods and Materials

The six sets of lamps were mounted to metals bars at 2.50m height in a darkened green house. Figure 3 shows the lamps and their specification as far as these specifications were available. The spectrometer used to measure the lamp emission was put on a platform on wheels transferable under the lamps. The spectral measurements were carried out using a spectrometer and a white spectralon reference panel. The spectrometer used is the FieldSpec Pro FR series no. 6395 manufactured by ASD (http://www.asdi.com) with a spectral range of 350 to 2500 nm divided over three spectroradiometers. The instrument has spectral sampling interval of 1.4 nm for 350 - 1000 nm and 2 nm for 1000 - 2500 nm. The spectral resolution is provided for 3 wavelengths and is specified as Full Width Half Max (FWHM) at 3 nm at 700 nm, 10 nm at 1500 nm and 10 nm at 2100 nm. The sensor has a fibre optic cable with an 8 degrees field of view. Since the emission of the lamps was not homogenized using a diffuser, the radiance was not measured directly by pointing the optical cable to the lamps but a spectralon white reference panel (Labsphere, 2012) was positioned approximately 1.5 meter under the lamps and next the optical cable was pointed to the reference panel. The spectralon reference panel approaches 100% reflectance throughout the solar spectrum.

The emisssion measurements were carried out by positioning the spectralon and spectrometer under the lamps. The lamps and spectrometer were first allowed to warm up for 30 minutes to obtain stable illuminations and instrument conditions. The ASD was set to average 50 measurements before the spectra were stored. Next to these 50 instrument averaged measurements we stored 5 individual measurements for each lamp and these 5 were averaged in order to reduce noise.

The emission of the lamps is measured by switching the ASD from 'Reflectance Mode' to 'Radiance Mode'. The radiance reported by the spectrometer is the calibrated radiance before the instrument was shipped by ASD Inc. The units are microwatt/cm^2/nm. The radiance values should be interpreted with care since the emission of the lamps was measured indirectly via the spectralon reference panel and there might be uncertainties in the instrument calibration (Hatchell, 2012).

Results

The results of the spectral emission measurements of the set of lamps are discussed in this section. Emphasis is put on the differences shape of the spectra i.e. peaks or maxima, valleys in the emission spectra and comparison with the other lamps. The absolute values should be interpreted with care and it preferred to consider only the differences in values rather than the watts.

Lampset 0 contains the Tungsten halogen lamp (50 W) and two theatre lamps of Wageningen University (each 1000 W) and two halogen lamps (each 300W) owned by the Physical Geography laboratory ('bouwlampen'). This experimental setup of lamps is also used to measure the spectral response of the perennial grass species *Holcus lanatus* under varying nitrogen and phosphate supplies (Loozen et al., in prep). The emission spectrum is shown in figure 4. This combination of lamps is the brightest of all sets and ranges up to 30 MicroWatt/cm^2/nm. The emission stays relatively high in the entire solar spectrum. In visible blue the emission spectrum increases fast to its approximate maximum around 1000nm. Beyond 1000nm it slowly decreases in brightness but stays considerable high until 2500nm.

Lampset 1 (White Plasma Lamp Alvara Series No. 201212-476 400 W) has approximately half the overall brightness of lamp set 0 with an overall average brightness of 0.02 MicroWatt/cm^2/nm invisible decreasing to 0.01 in NIR and SWIR. The spectrum is shown in figure 5. The lamp has however about 7 strong peaks of emittance at 410, 452, 509, 536, 569, 590, 819 nm reaching up to 0.15 MicroWatt/cm^2/nm. The peak at 536nm is brightest followed by the peak at 590nm. Emittance in NIR (700-1100) and SWIR (1100-2500) is low except for one peak at 819nm. The emittance at 410 nm and 452nm in visible blue corresponds well with the maxima of chlorphyll a and chlorophyll b absorption respectively. The lamp does not have peaks for the chlorophyll maxima in visible red near 640 and 670nm (Vand er Meer & De Jong, 2004).

Lampset 2 (no specifications are available) has the lowest overall brightness with approximately 0.007 MicroWatt/cm^2/nm in Visible light and decreasing to 0.001 MicroWatt/cm^2/nm in NIR and SWIR. Relative emission peaks are located at 440, 535 and 635nm. The emission spectrum is shown in figure 6.

Lampset 3 (no specifications available) is considerable bright in the visible wavelengths but emittance strongly decreases beyond 750nm. The spectrum of this lamp is shown in figure 7. Peaks in the spectrum are located at 442, 568, 645 nm. The two peaks at 442 and 645 correspond well with chlorophyll absorption maxima.

Lampset 4 (Lamp 4 Neon Philips SGR 102/400. Nr9102 572 400) has orange/yellow visible light, a modest overall brightness of around 0.003 MicroWatt/cm^2/nm. The spectrum is shown in figure 8. The lamp has a number of bright peaks (spikes) at 819 nm up to 0.30 MicroWatt/cm^2/nm and at 568, 584, 596 nm. The peaks are located in the orange (green/red) visible spectral regions and do not match the pigment absorption of chlorophyll but approaches the absorption maximum of Phycoerythrin. The lamp furthermore has a number of emission peaks at 1142, 1850 and 2207nm.

Lampset 5 (Lamp 5 Mercury Philips MGR 001| 400. Nr. 9102 572 401) has a typical peak or spike emission spectra that is shown in figure 9. Overall brightness is around 0.01 MicroWatt/cm^2/nm slowly decreasing from visbile wavelengths towards the SWIR. The peaks are located at 452, 536, 590 and 819 nm ranging up to 0.12 MicroWatt/cm^2/nm. The 452 is close to the chlorophyll b maximum absorption region.

The combined emission spectra of the 6 lamps are illustrated in figure 10. This graph allows easy comparison of the spectral behavior of the lamps. The strong overall brightness of the first lampset (0) is clearly visible. The peak and spike behavior and the relative brightness in visible, NIR and SWIR of the other set of lamps can be compared in this graph and provides information how well they match with pigment absorption as discussed above.

Conclusions

The first lamp set (lamp set 0) is superior for spectral measurements as it provides sufficient radiance throughout the spectrum. Especially when measuring reflectance of other objects than plants e.g. rocks, minerals and soils sufficient light is required in the SWIR especially the 2000-2500nm region. Lampset 1 and to a lesser extent lampset 2 has the best match with the pigment absorption maxima in the leaves of the plants. Lampset 0 covers the entire spectra and is very suitable for spectral measurements of plants and other objects but is not very energy efficient if the only aim is stimulating plant growth. The lamp emits vast amounts of energy not used by the plants.

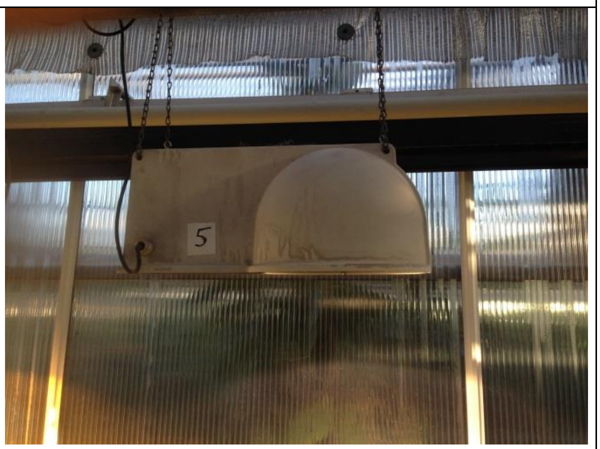
Lamp set 0: 3 halogen (50 and 2x300W) and 2 theatre lamps (1000 W).

Lamp 1: White Plasma Lamp
Alvara Ser No. 201212-476 400 W

Lamp 2: no specifications available

Lamp 3: no specifications available

Lamp 4: Natrium.
Philips SGR 102/400. Nr9102 572 400.



Lamp 5: Mercury
Philips MGR 001| 400. Nr. 9102 572 401.

Figure 3: The set of lamps available in the botanical garden of Utrecht University from which the emission spectra was measured using the ASD spectrometer.

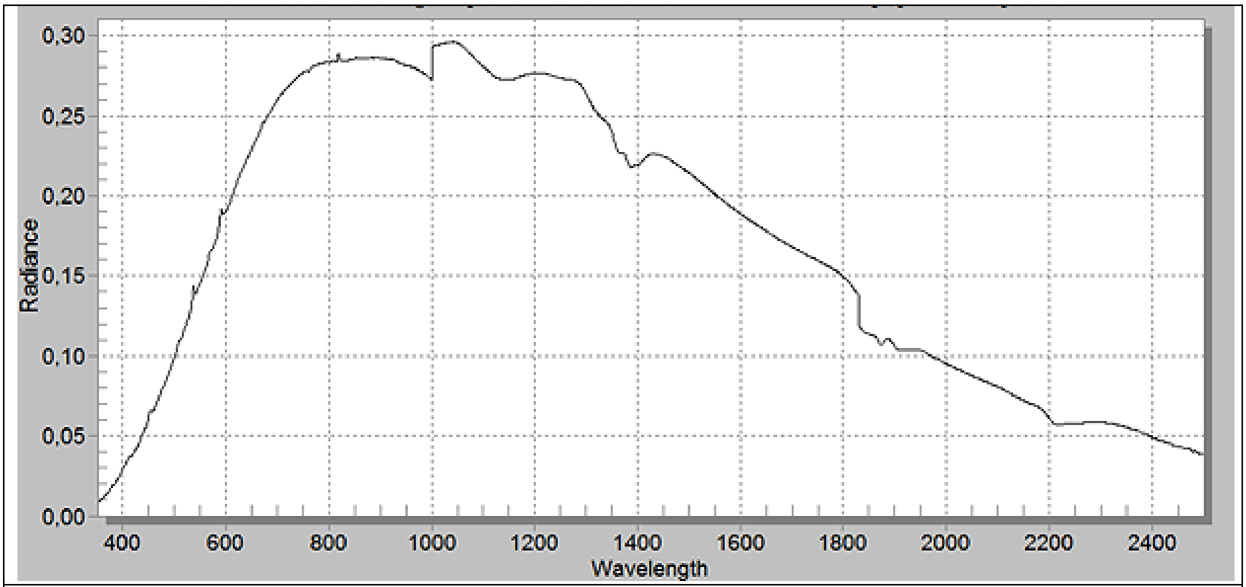


Figure 4: Lamp set 0 Wageningen tungsten halogen lamp, two theatre lamps and two DPG halogen lamps. Wavelength in nm and Radiance in MicroWatt/cm^2/nm.

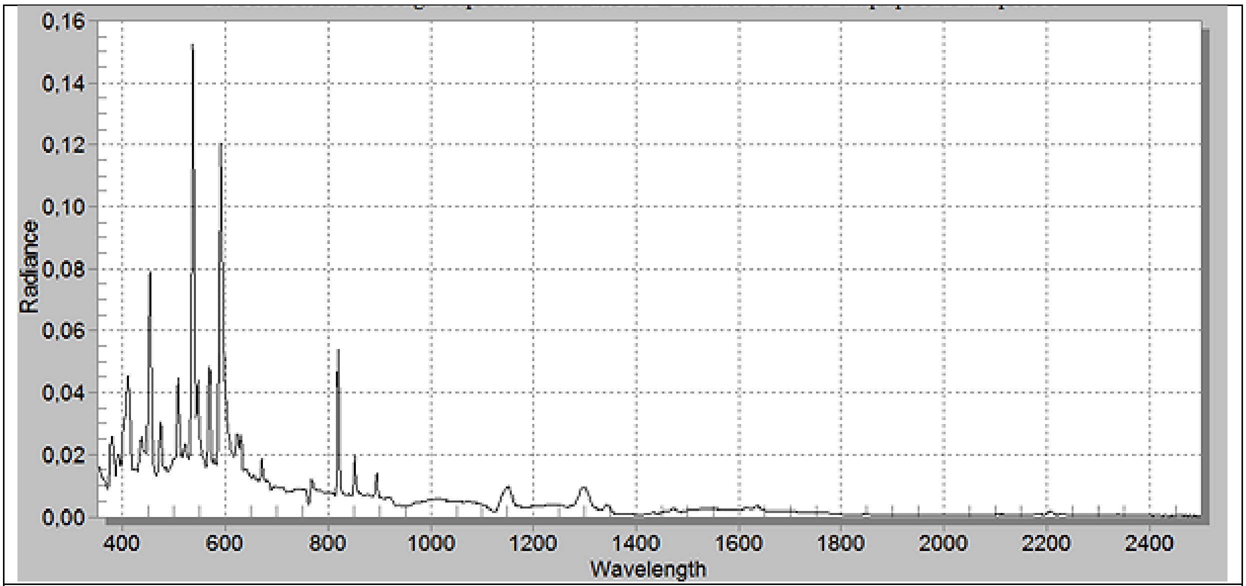


Figure 5: Lamp set 1 White Plasma Lamp Alvara Ser No. 201212-476 400 W. Wavelength in nm and Radiance in MicroWatt/cm^2/nm.

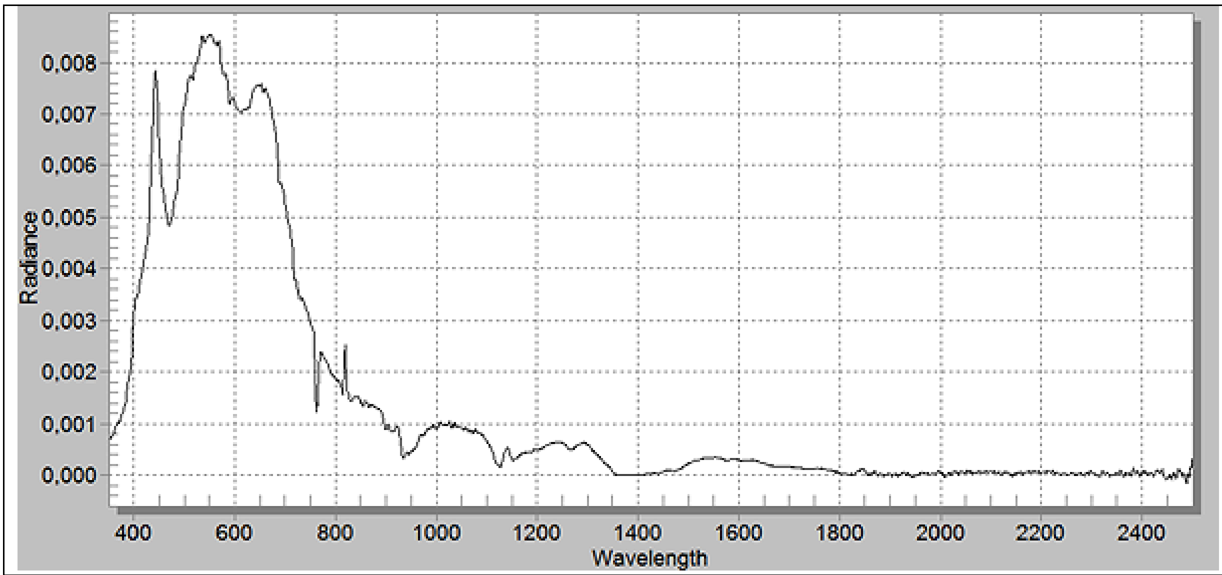


Figure 6: Lamp set 2 no specifications available. Wavelength in nm and Radiance in MicroWatt/cm^2/nm.

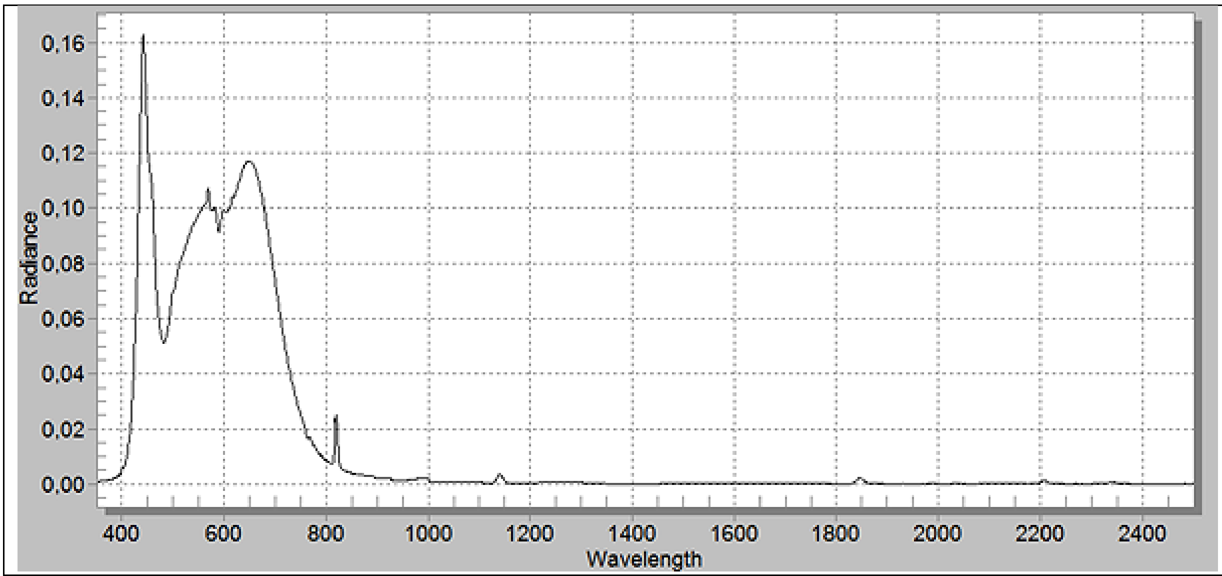


Figure 7: Lamp set 3 no specifications available. Wavelength in nm and Radiance in MicroWatt/cm^2/nm.

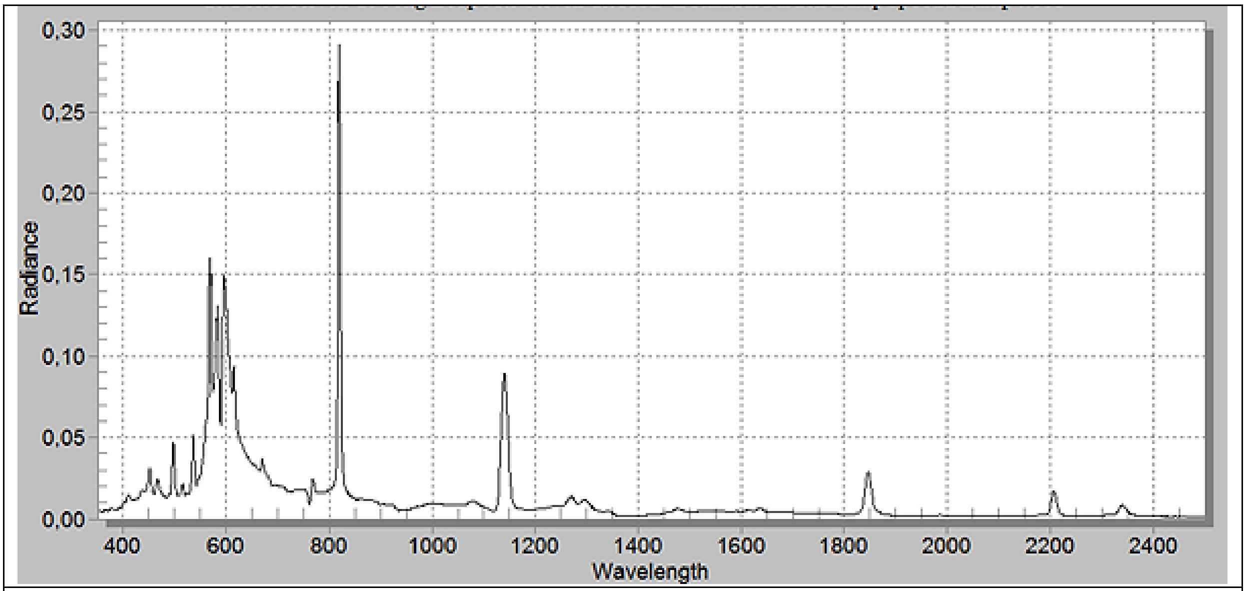


Figure 8: Lamp set 4 Neon Philips SGR 102/400. Nr9102 572 400. Wavelength in nm and Radiance in MicroWatt/cm^2/nm.

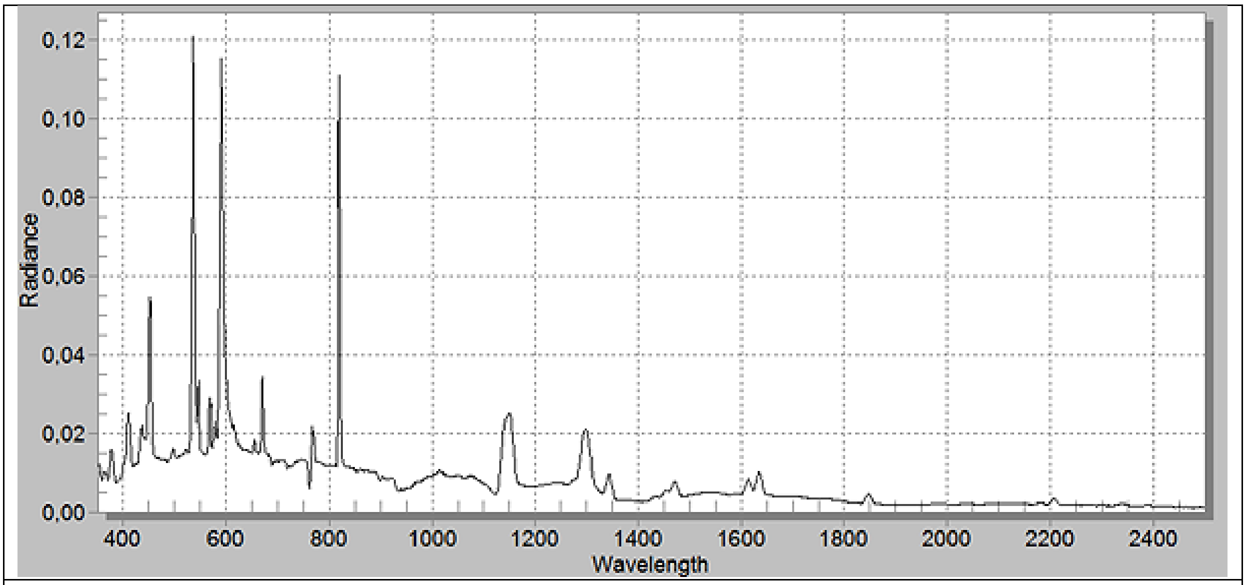


Figure 9: Lamp set 5: Mercury Philips MGR 001| 400. Nr. 9102 572 401. Wavelength in nm and Radiance in MicroWatt/cm^2/nm.

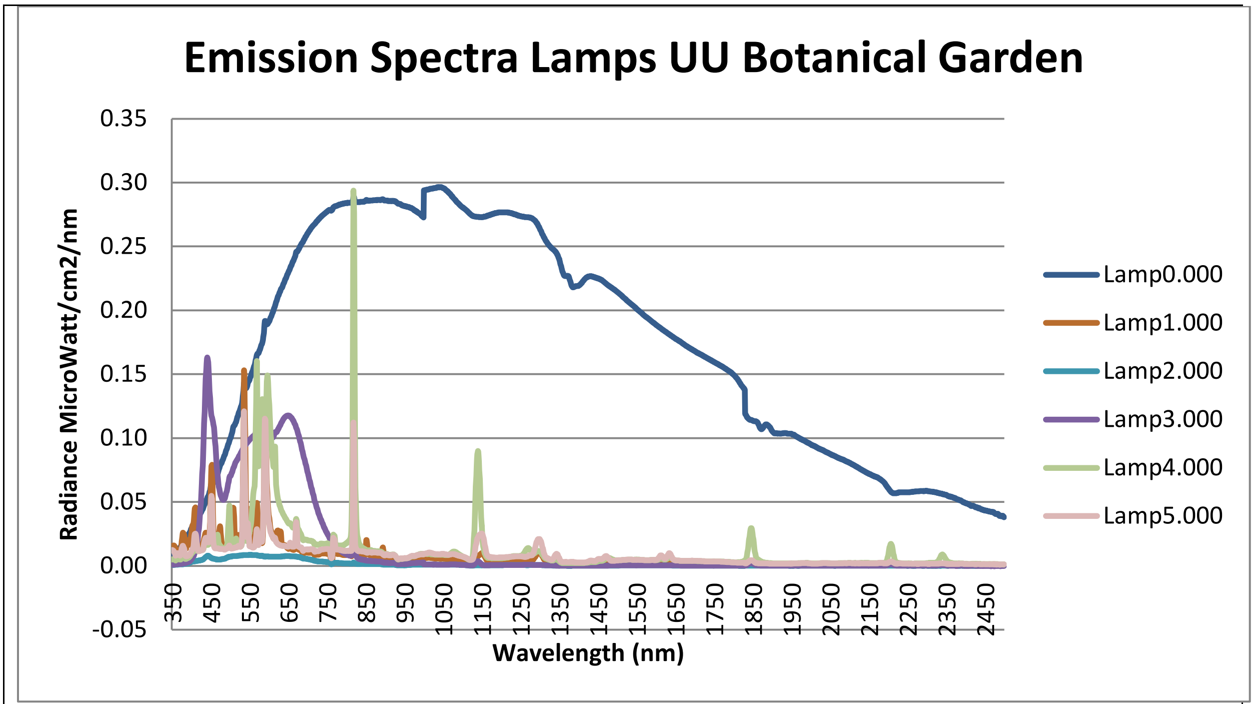


Figure 10: The combined spectra of the 6 lamp sets. Wavelength in nm and Radiance in MicroWatt/cm^2/nm.

Acknowledgements

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