Report on quality metrics and methodologies for spectral radiant flux measurements for Solid State Lighting use in greenhouses

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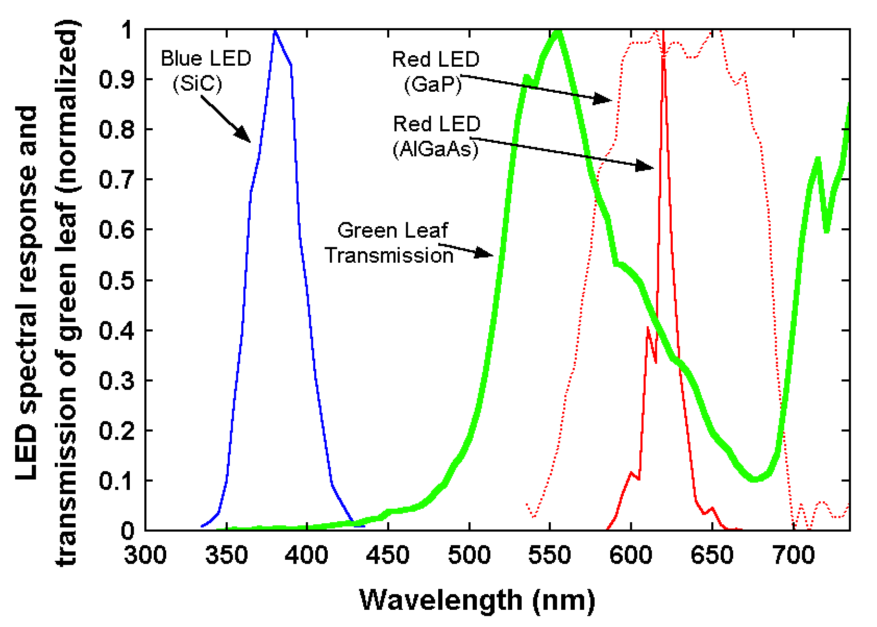
NPL, Teddington, 22-23 Apr 2013

Outline

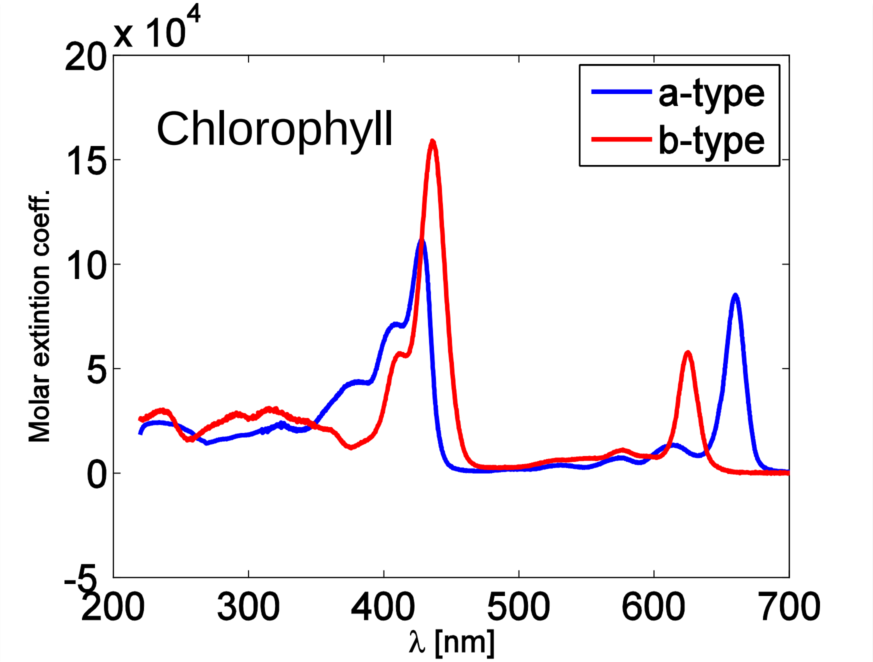
- Main goal
- Spectral response of plants
- What is a proper SSL source?
- Method for quality identification
- Degree of correlation and Alfa factor
- Conclusions

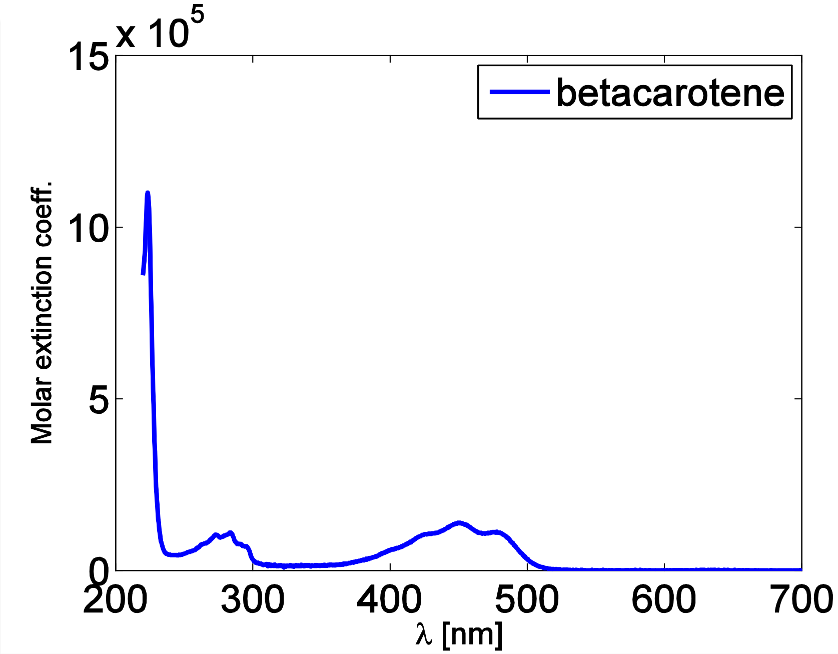
Main goal

To define proper parameters to quantify the spectral quality of a source for use in greenhouses



Spectral response of plants





- low level absorption in the green-yellow (500−600 nm) range
- the absorption at 400−500 nm is due beta-carotene

What is a proper SSL source?

The goal of any artificial lighting system:

To provide a light of proper irradiance and spectral composition

The metrology interest:

To quantify how good is the match between the source properties and plants needs

Methods to identify the quality of SSL

Degree of correlation between the spectral irradiance of a source s(λ) and the aimed spectral irradiance to be offered to a plant, r(λ) :

$$\gamma\left[r(\lambda), s(\lambda), \Delta\lambda\right] = \frac{\int_{\Delta\lambda} r(\lambda)s(\lambda)d\lambda}{\sqrt{\int_{\Delta\lambda} r^2(\lambda)d\lambda}\sqrt{\int_{\Delta\lambda} s^2(\lambda)d\lambda}}$$

γ= 1 only when S(λ) = r(λ) · c , c being a constant.

- only shape, no information on irradiance level

\+ easy to compute, clear physical meaning (it is just a distance on functions space)

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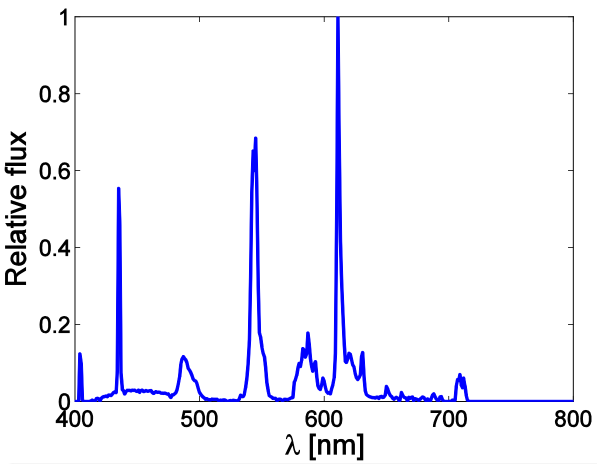
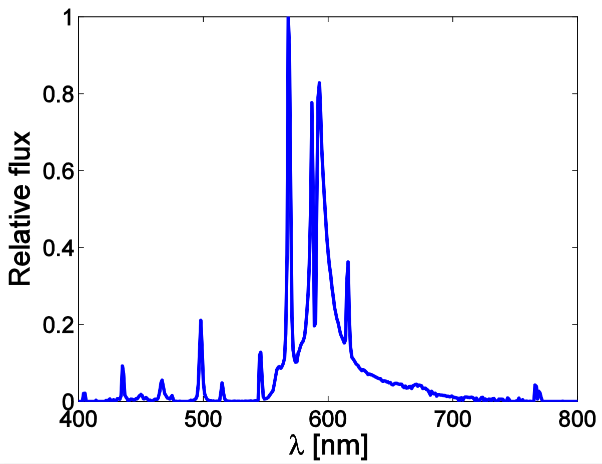
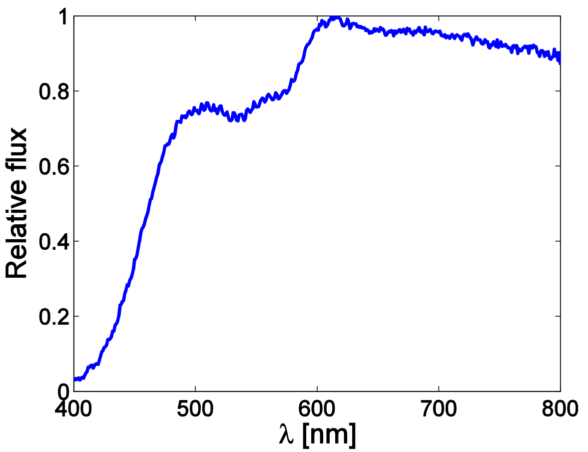
Is the degree of correlation enough?

white fluorescent tubes (FT)	high pressure sodium lamp (HPS)	microwave driven plasma lamp (MDPL)







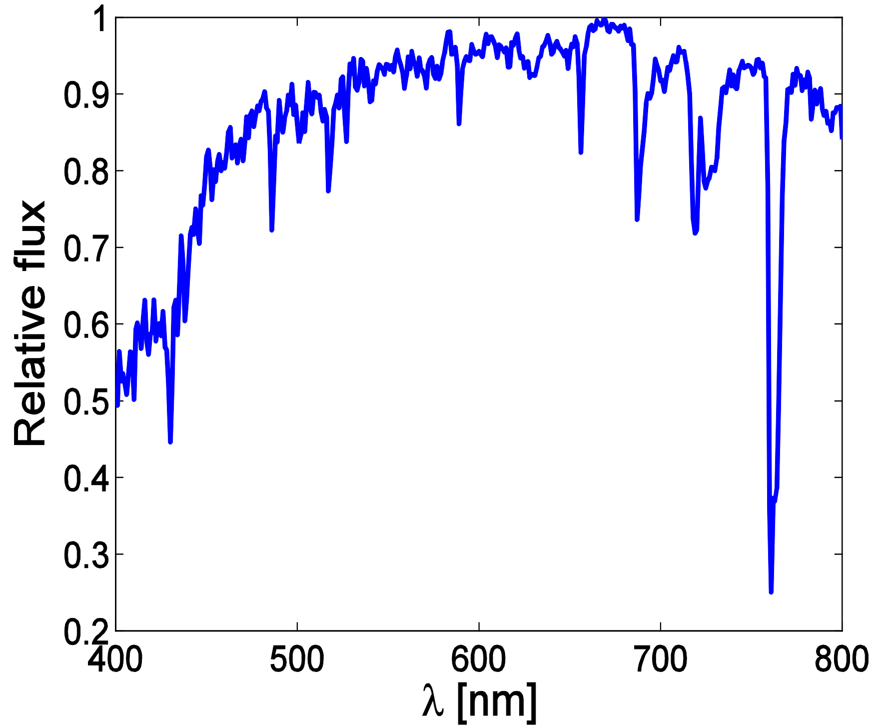
Let us quantify how close these spectra are to the solar spectrum

Is degree of correlation enough?

Solar spectrum.
Data from ASTM G-173

Three lamps studied
in the spectral range 400-800 nm:

γ(FT, SUN) = 0.30
γ(HPS, SUN) = 0.12
γ(MDPL,SUN) = 0.93



Alpha factor

Alpha factor is able to detect differences in irradiance of the two (otherwise identical) spectra.

$$\alpha = \frac{\int_{\Delta\lambda} \left| r(\lambda) - s(\lambda) \right| d\lambda}{\int_{X\lambda} r(\lambda) d\lambda} = \left| 1 - c \right|$$

α (MDPL, SUN) = 0.2

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Some experimental evidence

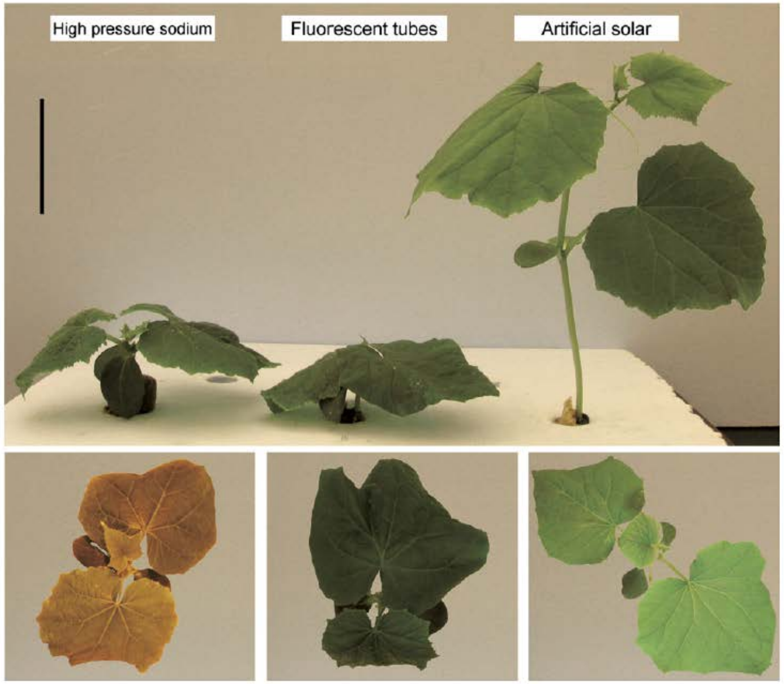

Fig. 2. Cucumber plants grown under a high pressure sodium lamp (left), fluorescent tubes (middle), and an artificial solar spectrum (right) 13 d after planting the seedlings. The upper image was made before the plants were dissected for growth and morphology analysis (bar=10 cm). The lower three images were made before harvest and are of plants different from those on the upper image. These three images are not scaled; the leaf colour appears unnatural due to the growth light environment.

S. W. Hogewoning, et al., *Journal of Experimental Botany,* **61**, 1267-1276, (2010).

Also the plant's morphology counts (!!), not only chemistry (shadow effects, etc)

Conclusions

- A proper aimed spectrum r(λ) should determined, *a priori,* by different means. This spectrum should prove to be the most suitable one to achieve a given goal.
- A light source, with the best overlap with such spectrum should be designed. SSL offer great flexibility for this.
- The degree of correlation is a tool that allows one to draw quantitative conclusion on how much a given source complies with the spectral needs of a plant.

As to measurement tools…

-No need of special measurement procedures
-Radiant flux of SSL (goniometric measurements) required or total radiant flux (sphere facility)
-Spectroradiometer with accuracy 0.1 nm and 1 nm spectral resolution is recommended.