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Light spectrum optimization for plant growth using biological feedback

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The use of light emitting diods (LEDs) as greenhouse illumination is increasingly common. When each LED color is individually dimmable both light spectrum and light intensity can be tuned, which opens up for optimisation of photosynthesis through automatic control of light quality and quantity. However, this requires a non-destructive biological growth signal that can be measured fast, remotely and preferably without interacting with the plants. A potential candidate signal is steady-state chlorophyll *a* fluorescence gain at 740 nm, defined as dF740/dq, i.e. the difference in fluorescence at 740 nm divided by the difference in incident light quanta caused by a (small) change in intensity of each individual LED color in the lamp (Ahlman et al., 2017). By automatically adjusting the spectrum, to aim for equal fluorescence gains for all LED colors (Wik et al., 2014), the instant photosynthetic rate can be optimised given a preset electric power input to the lamp. When implementing such a controller though, constraints on the spectral distribution are needed to minimise a negative impact on plant morphology.

In this study measurements were conducted (on cucumber and lettuce) under different background light, and at each setting excitation signals were sequentially added by each of six different LED colors (peak wavelength at 400, 420, 450, 530, 630 and 660 nm). The corresponding changes in steady-state fluorescence were measured with a spectrometer and the fluorescence gain (dF740/dq) was calculated for each LED color and at each background light setting. These fluorescence gains were compared in order to evaluate the different LEDs' relative effect on photosynthesis under each of the different background light settings. Additionally, the photosynthetic rate was measured by an infrared gas analyzer (IRGA) in a few sets and (in the same manner as the fluorescence gain) the photosynthetic rate gain was calculated. The light regimes investigated ranged from 160 to 1000 $\mu mol\ m^{-2}s^{-1}$. At each intensity level five different spectral distributions were applied, composed of different amount of red light, ranging from 50 to 100% of the total photon flux density and with a sustained green to blue ratio (g:b 1:2).

The mutual relation between the fluorescence gains corresponding to the different LED colors did not change significantly due to background light quality. The fluorescence gain was found to be highest in response to red LEDs (660 followed by 630) for both cucumber and lettuce and for all light settings. However, the relative size of the gains did change due to light quantity. Furthermore, it was found to be species dependent. These observations, i.e. the relative efficiency of enhancing the photosynthesis of the different LED colors, are in agreement with the action spectrum for cucumber and lettuce found by McCree, 1972.

An online controller, working continuously to find the optimal light spectrum given a preset electric power input to the lamp, seems not to be needed. However, we expect regular monitoring of the fluorescence gain throughout the growth cycle, to be useful. For example, to detect diverse degradation of the LEDs, or to identify where the light curve saturates. In previous work (Carstensen et al., 2016) we have shown that the dynamics of the fluorescence response to changed incident light, varies with the status of the plant, for example due to light inhibition. Further research aims at identifying if light inhibition, salt stress, biotic stress and draught, can be observed as changes in the mutual relation of the steady-state fluorescence gains.

References

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