Modelling chlorophyll fluorescence signals for greenhouse LED-lighting control

A-M. Carstensen[1], T. Wik[1], J. Lindqvist[2], D. Bånkestad[2]
[1]Chalmers University of Technology, Göteborg, Sweden; [2]Heliospectra AB, Göteborg Sweden.

Abstract
Artificial lighting control in industrial scale greenhouses has a huge potential for increased crop yields, energy savings and production timing. Today's control of greenhouse lighting generally constitute manual on/off control, due to the limited actuation capacity of the HPS lamps, traditionally used. With LED-lamps developed for greenhouses and recently introduced on the market, advanced lighting control of both the spectrum and the intensity of light can be achieved. However, still it remains a challenge to measure the plants' capacity of utilizing light and control the light accordingly. Detecting the plants' capacity of utilizing light is a key issue, since up to a certain limit an increased light intensity leads to increased photosynthesis, while exceeding this capacity limit leads to inhibition of photosynthesis, i.e. *photoinhibition*, that can significantly reduce the photosynthetic yield and hence, production.

A widely used tool for measuring photosynthesis and photoinhibition non-invasively is light induced chlorophyll fluorescence. Traditional methods detect the fluorescence response to fast repetition light pulses and compares the response amplitude at different conditions (such as dark acclimated, light saturated and 'normal' light conditions). However, existing fluorescence based methods require use of fully saturating light, which has proved hard to obtain for a whole plant canopy, furthermore they require pre-darkening of leaves, which is impossible to obtain at daylight in a greenhouse. Differently from the methods traditionally used, we are developing a method that detects changes in the dynamics of the fluorescence responses to light excitation. The dynamics of the fluorescence signal is affected by the available metabolite pool sizes (e.g. the amount of photosynthetically active and available photosystems, enzyme concentrations etc.) and by internal regulation of photosynthesis, such as protection against excess light through regulated heat dissipation (i.e. *photoprotection)*. Hence, studying the fluorescence dynamics will provide valuable information on photosynthesis, photoprotection and photoinhibition.

In our earlier work we studied the fluorescence response to a step excitation at three different ambient light intensities (110, 500 and 1750 µmol $m^{-2}s^{-1}$ photon flux density (PFD)) from Basil plants (*Ocimum basilicum*) grown under three different light intensities (80, 250 and 500 µmol $m^{-2}s^{-1}$ PFD). Based on studying the frequency function of black-box models estimated to the step response data, we concluded that i) acclimation to high growth light moved the frequency function towards lower frequencies, ii) increased ambient light intensity moved the frequency function towards higher frequencies, iii) at ambient light intensities above the growth light intensity the complexity of the response was decreased, and iv) long-term irreversible photoinhibition decreased the amplitude of the resonance of the frequency response.

In later experiments we have studied fluorescence responses to step excitation at ten ambient light levels in the range of 100-1700 µmol $m^{-2}s^{-1}$ PFD, and from both basil (Ocimum basilicum) and lettuce (Lactuca sattiva) acclimated to 190 µmol $m^{-2}s^{-1}$ PFD. Our new findings confirm, that the frequency function is successively moved towards higher frequencies when the ambient light intensity is

increased. Furthermore, we could define more precisely where the loss of complexity occurres. At low light conditions an Output Error (OE) model with 3 poles and 3 zeros gave the best fit to data in simulation. This model order was found appropriate for basil in the range of 100 to approximately 500 µmol $m^{-2}s^{-1}$ PFD, and for lettuce in the range of 100 to 300 µmol $m^{-2}s^{-1}$ PFD. At light intensities above these, the model order could be decreased to 2 poles and 2 zeros, but at three times the acclimation light intensity (i.e. at 600 µmol $m^{-2}s^{-1}$ PFD), the model order required for lettuce decreased to 1 pole and 1 zero. The corresponding decrease in complexity for basil occurred at approximately four times the acclimation light (i.e. at 800 µmol $m^{-2}s^{-1}$ PFD). Based on this, different feedback signals are possible, such as optimal model order, resonance frequency, or tracking of the phase at a certain frequency.