FAR RED GROWERS GUIDE

GrowFlux

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Overview

What is far-red light?

Plants utilize different wavelengths of light with varying efficiency, peaking in the red and blue regions of photosynthetically active radiation (PAR) (400 - 700 nm). Far-red light (> 700 nm) is at the very edge of PAR and the visible spectrum. Although, photosynthetic efficiency falls sharply for wavelengths longer than 685 nm, far-red light enhances the photosynthetic efficiency of shorter wavelength light (Zhen & van Iersel, 2017).

What is the red to far-red ratio?

Red (600-700 nm) and blue (400-500 nm) wavelengths are the most photosynthetically active, while far-red light is much less efficient at driving photosynthesis directly. While red and blue light are absorbed in the upper canopy, a larger relative proportion of far-red light is reflected and transmitted to the lower canopy. The spectral quality of the light changes in the shade condition of lower canopy. Specifcially, low overall light intensity and low red to far-red ratio at the apex of the plant induces a shade avoidance response (stem extension, leaf expansion, apical dominance) in many crops.

Why is far-red light important?

Far-red light boosts photosynthetic efficiency. Throughout a plant's life cycle, the effect is additive, enhancing plant health and yeild. Precise control over the red to far-red ratio enables growers to affect a number of phytochrome regulated plant responses (see page 4) including early leaf expansion and flowering. Growing with far-red light gives growers the means to grow a higher quality crop faster.

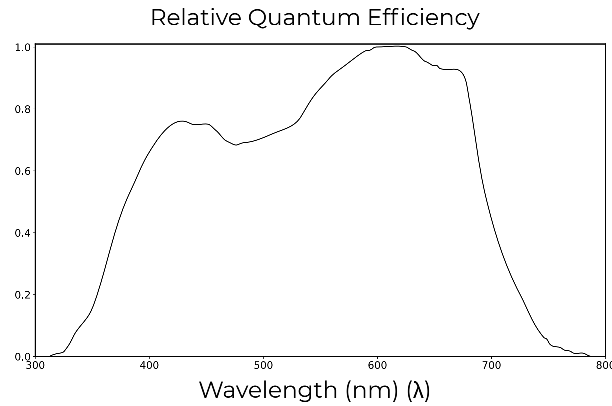

Figure 1 - Relative Quantum Efficiency
Relative quantum efficiency (RQE) is a measure of photosynthetic efficiency by wavelength, expressed as moles of carbon fixed per mol of photons absorbed per wavelength (McCree, 1972).

Far-red light increases crop quality and reduces time to harvest.

GrowFlux helps you leverage far-red light.

GrowFlux takes the guesswork out of far-red lighting control. GrowFlux lighting controls track fixture output in horticultural units and calculates valuable statistics that keep you informed of your crop's health in real time. With a user experience built for horticulture, the Growflux platform includes pre-built light formulas that put advanced far-red lighting control at your fingertips.

GrowFlux takes the guesswork out of far-red lighting control.

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Fine Tuning Plant Response via Phytochrome Photoequilibrium

Plants perceive the red to far-red ratio via the phytochrome photoreceptor, which regulates morphogenesis and flowering in photoperiodic crops. Phytochrome photoequilibrium (PPE) provides a quantitative estimation of the action of red to far-red ratio on a crop. Growflux light formulas calculate PPE for any spectrum, which makes it easy for cultivators to leverage desirable plant response to dynamic light environments.

Phytochrome photoequilibrium (PPE) can be used to estimate plant responses to a given red to far-red ratio.

What is Phytochrome Photoequilibrium?

The phytochrome photoreceptor exists in two interconvertible forms, a red-absorbing form (Pr) and a far-red absorbing form (Pfr). Upon absorbed red radiation, Pr converts to Pfr. Similarly, upon incident far-red radiation or a prolonged dark period, Pfr converts to Pr. The integrated product of a given spectral photon distribution (SPD) and the absorbance curves for each form of phytochrome estimate the relative quantities of Pfr and Pr (1, 2) (Sager et al., 1988). The absorbance curves for each form of phytochrome overlap, so the relative proportion of each form reaches equilibrium at a given SPD. PPE is calculated as the ratio of Pfr to the sum of Pfr and Pr (3) (Sager et al.,1988). PPE ranges from 0.73 in sunlight to 0.15 in vegetated shade and is closely correlated to red to far-red ratio. PPE can be used to estimate morphological and developmental plant responses to a given SPD (Park & Runkle, 2017).

Precise control of PPE enables the following cultivation techniques:

1. A low red to far-red ratio in early vegetative growth promotes **early leaf expansion** which **increases radiation capture and thereby yield .**

2. Precise control of red to far-red ratios during flowering of photoperiodic crops **enhances the quality of flowering response**.

3. A small absolute quantity of far-red light delivered during the photoperiod **boosts yield and quality** over the course of the crop's life cycle.

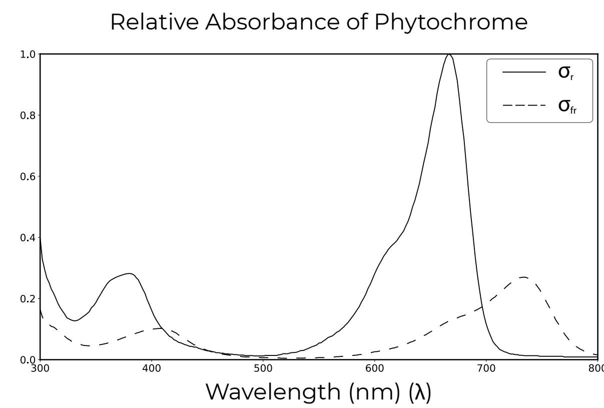


Figure 2 - Same phytochrome, two different relative absorbances
Phytochrome exists in two interconvertible forms, a red-absorbing form (σ_r) and a far-red absorbing form (σ_{fr}). The absorbances overlap, which causes the relative proportion of each form of phytochrome to reach equilibrium for a given incident spectrum.

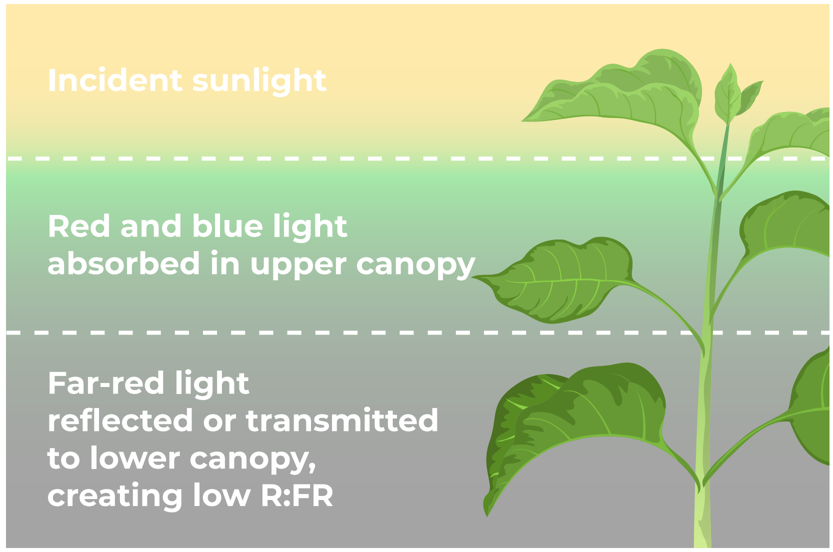
$$(1)\quad Pr = \sum_{300}^{800} N_\lambda \, \sigma_{\lambda r}$$

$$(2)\quad Pfr = \sum_{300}^{800} N_\lambda \, \sigma_{\lambda fr}$$

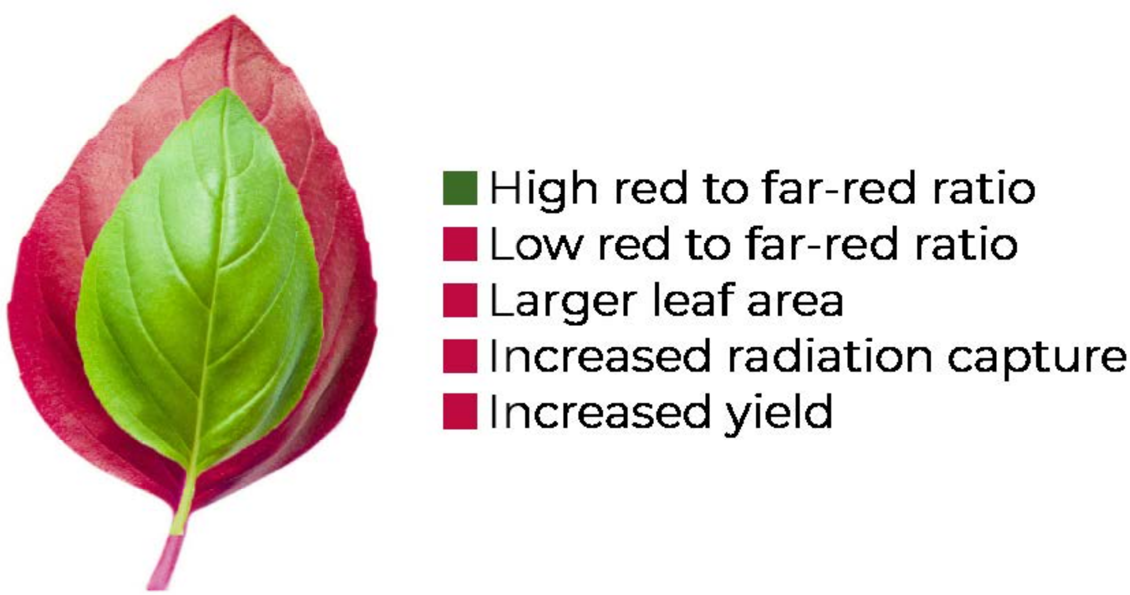
$$(3)\quad PPE = Pr\,(Pr + Pfr)^{-1}$$

Early Leaf Expansion: Increased Radiation Capture Boosts Yield

Shade Avoidance in Natural Conditions

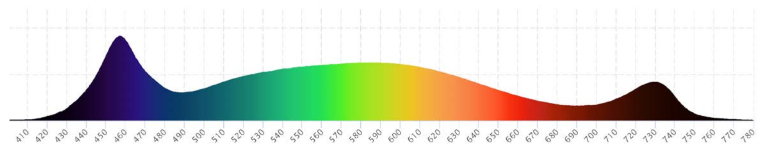


The spectral quality of the light environment varies at different heights under a mature plant canopy. Red light is absorbed in the upper canopy, while far-red light is reflected or transmitted to the lower canopy. The phytochrome apparatus perceives the relative decrease in red to far-red ratio in the lower canopy and induces a shade avoidance response that includes stem extension, leaf expansion, and apical dominance (Runkle & Park, 2017). A plant's ability to absorb a given quantity of light (radiation capture efficiency) is dependent on its leaf area, which, if reduced, will correspond with reduced growth (Bugbee, 2016). Early leaf expansion confers increased radiation capture throughout the crop life cycle, which boosts the efficacy of electric light and translates to increased carbon assimilation. Blue light in combination with low PPE can mitigate excessive shade avoidance due to reduced PPFD while allowing for leaf expansion (Runkle & Park, 2018). Care must be taken to carefully regulate the duration of low R:FR light as to balance leaf expansion with stem extension. GrowFlux lighting control puts this high level of precision at your fingertips.

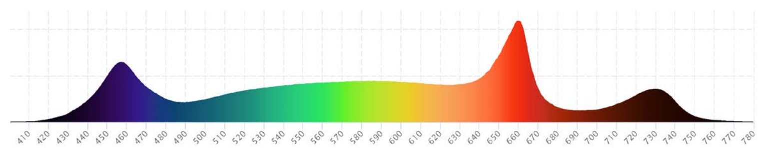


Flowering Faster with Far-red Light

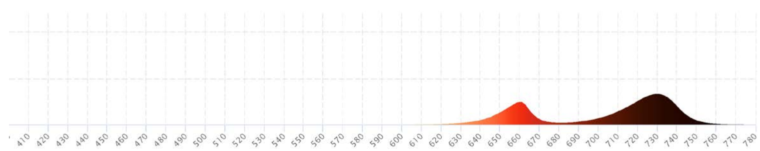
Photoperiodic crops exhibit a flowering response to a cultivar specific critical night length (Craig & Runkle, 2013). Photoperiodism falls within three broad categories: short-day, long-day, and day-neutral. Long-day plants flower in response to short nights, while short-day plants flower in response to long nights, and photoperiod does not affect flowering in day-neutral plants.



Moderate intensity, low red to far-red ratio (low PPE) accelerates flowering.



High intensity, high red to far-red ratio (high PPE) leverages the Emerson effect.



Low intensity, end of photoperiod, low red to far-red ratio (low PPE) enhances the flowering response.

The phytochrome photoreceptor perceives short days via phytochrome photoequilibrium (PPE) which is affected by both the red to far-red ratio and the critical night length. Under long-day conditions, PPE increases, which inhibits flowering in short-day crops. At the onset of short-days, Pfr converts to Pr during the dark period, thereby lowering PPE and inducing the flowering response in short day crops.

By maintaining a low red to far-red ratio during vegetative growth, growers can reduce the time to flower in short-day crops (Craig & Runkle, 2013). Precise control over PPE can affect the timing, quality, and quantity of the flowering response. To the contrary, inclusion of red light during early vegetative growth can delay the flowering response in short-day crops (Craig & Runkle, 2013). Furthermore, far-red radiation at the beginning and end of the photoperiod further promotes the flowering response by keeping PPE low.

In repeated tests conducted by GrowFlux's collaborators, far-red light delivered at the end of the photoperiod consistently resulted in 13-16% faster time to harvest for short day flowering crops.

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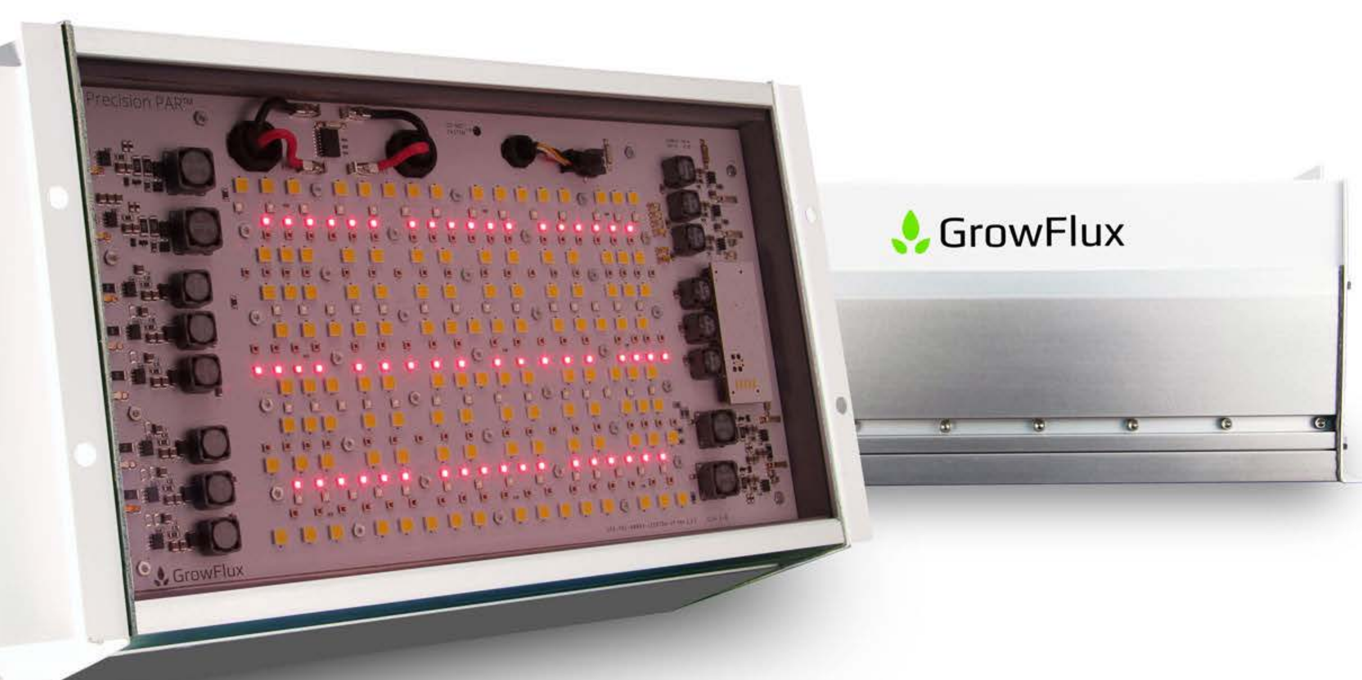
The Emerson Effect: How Far-red Light Boosts Photosynthetic Efficiency

Eliminating bottlenecks is the key to profitability – in your systems, your genetics, your workforce, and your processes. The photosynthesis process is no different; leveraging the Emerson Effect with far-red light eliminates a major bottleneck often overlooked by growers since it occurs within the plant tissues with non-visible light. We tested many grow lights with and without far-red light during the photoperiod. In all cases. broad spectrum lights with a small amount of far-red during the photoperiod yielded 10-15% higher than lights that didn't include far red light.

Broad spectrum lights with a small amount of far-red during the photoperiod yielded 10-15% higher than lights that didn't include far-red light.

What is the Emerson Effect?

Known as the Emerson effect, supplementation of far-red light amplifies the photosynthetic efficiency of shorter wavelength light. Throughout the crop life cycle, the effect accumulates, resulting in healthier plants and increased yield. Far-red light balances the excitation of photosystem II, boosting the photosynthetic efficiency (quantum yield) of shorter wavelengths (Zhen & van Iersel, 2017). Increased quantum yield translates into increased carbon assimilation (yield) and increased crop quality. Far-red light can increase net photosynthesis by 20% (Zhen & van Iersel, 2017).



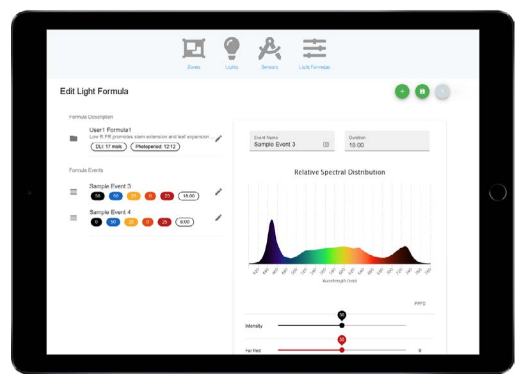
Controlling Far-Red Light

GrowFlux's mission is to bring intelligent horticultural lighting technology to growers of any skill level and scale to improve profitability and foster resource efficiency. Leveraging far-red lighting strategies is easy with GrowFlux's platform, which includes reliable wireless controls for any light, an ecosystem of horticultural sensors and software, and an extensible API to integrate controls across systems. Lighting manufacturers can bring tunable lighting products to market rapidly with specialized built in solutions including firmware and hardware modules.

GrowFlux offers tunable lighting controls for any fixture and an ecosystem of software and sensors built for horticulture. Whether you are a grower, lighting manufacturer, or integrator, GrowFlux has a control solution for your needs.

GrowFlux Access Point:
Link up to 500 lights or dimmers

GrowFlux dimmer:
Schedule & dim any 1-2 channel light with the waterproof GrowFlux Dimmer.
Connects up to 50 lights



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Appendix

Photosynthetically active radiation (PAR)
Flux density of wavelengths of light between 400 and 700 nanometers, measured in units of moles per square meter per second. (Barnes et al., 1993).

Photochemical cross-section of phytochrome
The absorbance by wavelength of each form of phytochrome of different spectral photon distributions (Smith, 1983).

Photomorphogenesis
The influence of light (quality, quantity, direction) on the morphological development of plants (Briggs & Olney, 2001).

Photoperiodism
Photoperiod crops exhibit a flowering response to a cultivar specific critical night length (Runkle, 2013).

Phytochrome
A class of photoreceptor that regulates numerous developmental effects including photomorphogenesis and flowering (Runkle & Park, 2017).

Phytochrome photoequilibrium (PPE)
The ratio of the far-red absorbing form of phytochrome to the total phytochrome pool (Sager et al.,1988).

Long-day plant (LDP)
Long-day plants flower in response to short nights (long-days).

Quantum yield
Quantum yield is a measure of photosynthetic efficiency, expressed as moles of carbon fixed per mol of photons absorbed (McCree, 1972).

Relative quantum efficiency (RQE)
Photosynthetic efficiency (mol CO2 per mol of incident light) as a function of the wavelengths of incident light. Photosynthetic plants have peak photosynthetic efficiencies in the red and blue regions of the visible spectrum (McCree, 1972).

Short-day plant (SDP)
Short-day plants flower in response to long nights (short-days).

Spectral photon distribution (SPD)
For a given light source, spectral photon distribution is the energy flux per square meter per second per nanometer (Barnes et al., 1983).

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