



By Erik Runkle and Bruce Bugbee



Problems with Foot-candles, Lux and Lumens

There are three ways to describe light intensity, but only one of them is appropriate for photosynthesis. Increasing use of light-emitting diodes (LEDs) means that the appropriate unit for light measurement is more important than ever. Although light quality and timing are powerful tools for altering plant shape, light intensity provides the horsepower to drive photosynthesis.

Photometric: Foot-candles and lux. These units of measurement are based on the perceived brightness to the human eye. Our eyes perceive green and yellow light much better than blue or red light, so this measurement system is completely biased toward people and is not appropriate for plants. Since most lighting applications are for people, this system is used by lighting professionals and utility companies, who usually optimize lighting for people. Therefore, the efficiency of lamps is almost always reported as the luminous efficacy, which is the number of lumens per watt of energy. (One lumen per square meter equals one lux, and there are 10.8 lux per foot-candle.)

Radiometric: Watts. This unit is used to determine the energy input and output of lighting applications. It describes the power of light that a light source emits or consumes. The light energy increases as wavelength decreases, so it takes more energy to make blue light than red light. Thus, this measurement system is based on power and is used to predict the heating value of light. It is not specific to plants or people.

Quantum: Moles of photons. The Stark-Einstein Law tells us that one photon excites one electron in photosynthesis, regardless of color, so counting photons is the

best way to predict photosynthesis. The number of photons in the photosynthetic waveband (400 to 700 nm) is typically reported as micromoles per square meter and second, or $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. This system considers all colors of light equally and is the most appropriate way to measure light intensity for photosynthesis and plant growth. Measuring moles of photons is not biased toward human vision; in fact, an intensity of deep blue and deep red light that appears dim to us can be bright light for plants.

Measuring light intensity in foot-candles or lux is especially unsuitable when using LEDs for plant growth. Blue and red LEDs are most often used for plant lighting because:

1. They are the most energy-efficient colors of LEDs
2. They are considered to be more photosynthetically efficient than green or white light
3. The addition of 10 to 20 percent blue light to red light produces a more “normal” plant shape; most plants grown under only red light are elongated.

However, since we don't perceive either blue or red light as well as green and yellow light, the luminous output of blue and red LEDs is low and they look dim (Table 1). Don't let your eyes mislead you; lamps that emit these wavelengths can deliver bright light for plants.

There is an even more dramatic difference in measuring horticultural lighting in lumens/foot-candles/lux versus $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ when delivering far-red light. To us, far-red light (around 730 nm) is barely perceptible yet it is necessary for photoperiod extension lighting of some crops. This difference is apparent with both incandescent lamps and far-red LEDs; their luminous output is low compared with their output in photons.

For these reasons, the horticultural industry should discontinue use of photometric units such as lumens, lux and foot-candles. These units are based on people's perception of light and are a highly misleading indicator of plant growth and flowering applications. We need to work with lighting professionals and utility companies to develop and adapt plant lighting standards based on photons and not lumens. 

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Table 1. Comparison of the photosynthetic photon efficiency (for plants) and the luminous efficiency (for people) of four light sources. Metrics based on lumens (lux and foot-candles) are highly misleading and inappropriate for plant applications.

Light source	Photon efficiency ($\mu\text{mol}\cdot\text{J}^{-1}$)	Luminous efficiency ($\text{lm}\cdot\text{W}^{-1}$)
Cool-white fluorescent	1.2	90
High-pressure sodium	1.6	130
Blue LEDs (peak=455 nm)	1.8	47
Red LEDs (peak=655 nm)	1.7	17