Is supplemental green light necessary for plant growth and development?

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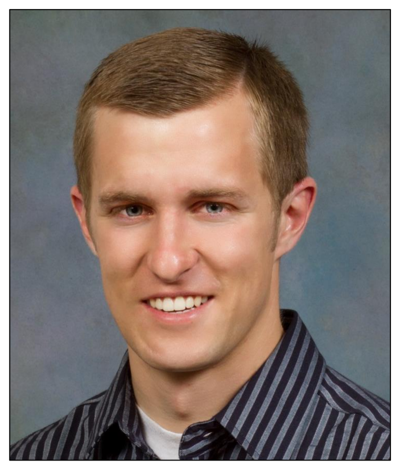

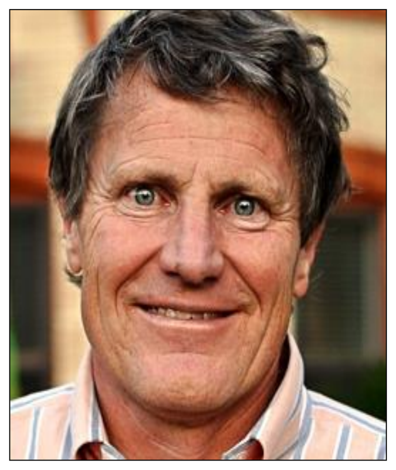

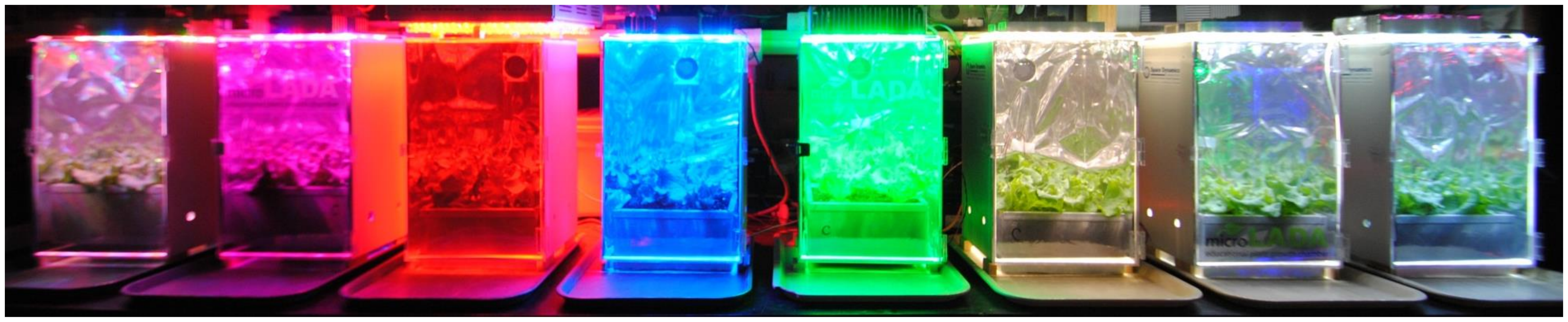

INTRODUCTION

Photosynthesis is driven primarily by photosynthetically active radiation (PAR), which ranges from approximately 400 to 700 nm. PAR is measured using photosynthetic photon flux (PPF, µmol photons m^{-2} s^{-1}), which gives equal weight to all photons within the PAR range. Surprisingly, not all wavelengths of photons are equally efficient in driving photosynthesis. The relative quantum efficiency (RQE) curve (Figure 1) indicates that red light (600 to 700 nm) is 25 to 35% more efficient than blue light (400 to 500 nm) and 5 to 30% more efficient than green light (500 to 600 nm) in driving photosynthesis [1].

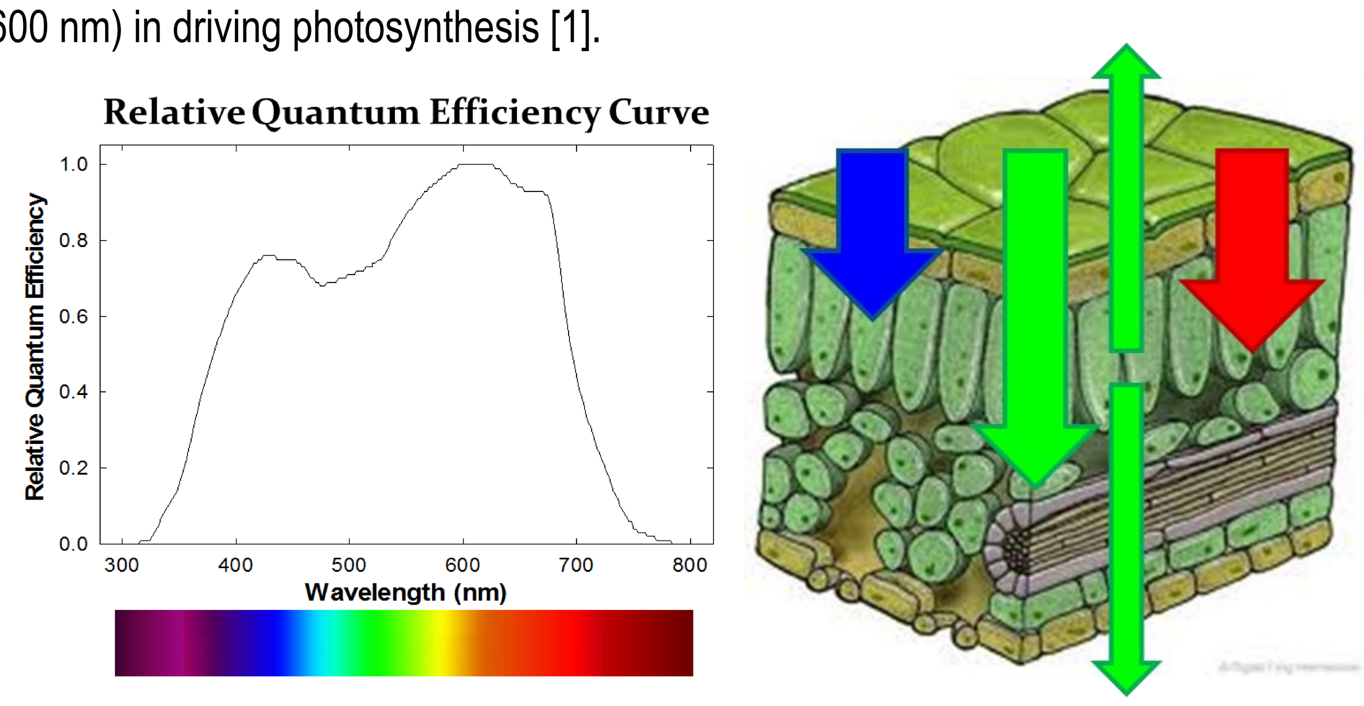

Figure 1. *Left: The relative quantum efficiency from 300 to 800 nm (adapted from [1]); Right: Blue, green and red light leaf penetration is illustrated.*

A theoretically more accurate measurement of PAR is therefore the yield photon flux (YPF), which is derived from weighting each photon's wavelength using its RQE. The RQE curve, however, was determined using single leaves at low PPF and therefore may not be representative of whole plants grown at high PPF. It also indicates only the theoretical photosynthetic efficiency without taking into consideration the combined effects of wavelength (light quality) on both photosynthesis and photomorphogenesis.

Although red light has the highest RQE, most plant species require blue light for normal development [2]. Like blue light, green light may also affect plant development [3], but its effect on photosynthesis is better studied. Two studies have reported that whole plant growth is increased when some green light is substituted for red light [4, 5]. These findings are supported by studies on single leaves which demonstrated the following:

- Green light drives CO_2 fixation deeper in leaves than red and blue light [6].
- In a strong white light background, green light drives photosynthesis more efficiently than red light [7].

The results of these studies indicate that green light is potentially a valuable component of light sources used for growing plants. However, the whole plant studies [4, 5] used relatively low PPFs (150 and 300 µmol m^{-2} s^{-1}, respectively), and the results may not apply to higher PPFs (e.g. 500 µmol m^{-2} s^{-1}).

MATERIALS & METHODS

We grew lettuce and radish under multiple LED treatments (Figure 3; Table 1) at two PPFs (200 and 500 µmol m^{-2} s^{-1}). Environmental conditions and root-zone environment were uniformly maintained across treatments. For both species we completed three replicate studies in time. In each replicate study, four plants were grown for 21 days, at which point canopy closure occurred. Prior to harvest, we measured relative chlorophyll concentration (CCI). At harvest, we measured fresh mass (FM), leaf area (LA), leaf number, and stem length (SL). All plant material was then oven-dried for ~48 hours and then dry mass (DM) was measured. For all growth and developmental parameters measured, we completed a two-way ANOVA statistical analysis using the PROC-GLM package in SAS v9.3. We also have completed two replicated studies with pepper which was transplanted into the same LED treatments as above but at a later growth stage. The studies with pepper helped elucidate the value of green light after canopy closure has occurred.

RESULTS & DISCUSSION

Monochromatic LED Treatments (Red, Green, and Blue)

In the red and green monochromatic LED treatments at both PPFs, lettuce and radish exhibited a severe shade-avoidance response, which resulted in significantly elongated stems and thin, chlorotic leaves. As a result, these treatments were unable to establish a strong leaf canopy and their growth (DM gain) was significantly jeopardized compared to the broad spectrum LED treatments (Figure 2). Lettuce and radish under the monochromatic blue LED treatment developed normally; however, the sole range of photons available to them were the least efficient, which resulted in significantly reduced growth. Pepper developed normally under all three treatments.

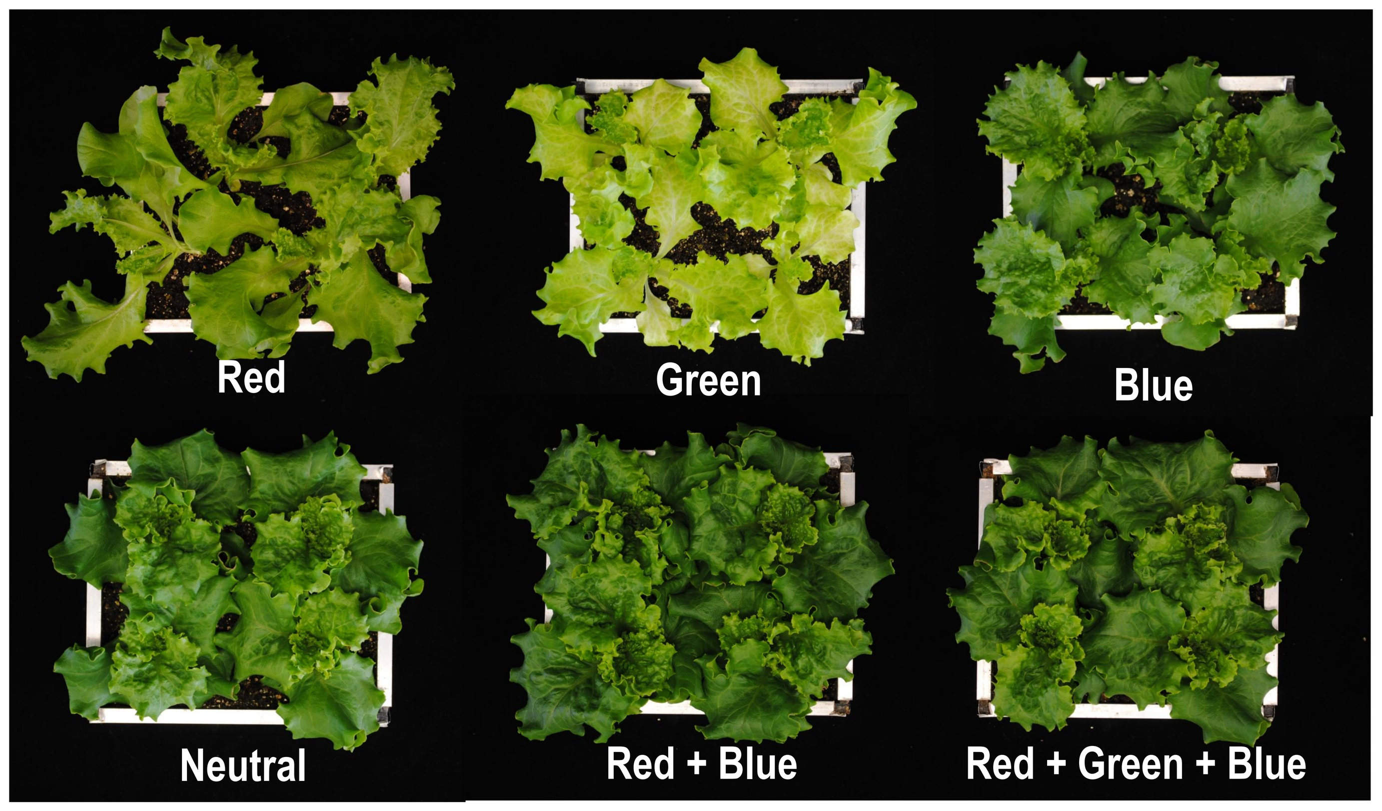

Figure 2. *Overhead view of lettuce from six LED treatments at 21 days (labeled below).*

Broad-Spectrum LED Treatments (Cool, Neutral, Warm, RB, RGB)

In broad spectrum light, supplemental green light was detrimental for both lettuce and radish, but did not affect pepper (Figure 4). In the low PPF treatments, supplemental green light was less detrimental, and in some cases beneficial. For lettuce and radish, the best treatment in terms of growth at 500 µmol m^{-2} s^{-1} was the RB treatment; conversely, at 200 µmol m^{-2} s^{-1}, neutral white LEDs were equal or better than the RB LEDs. All treatments were nearly equal for pepper (Figure 5).

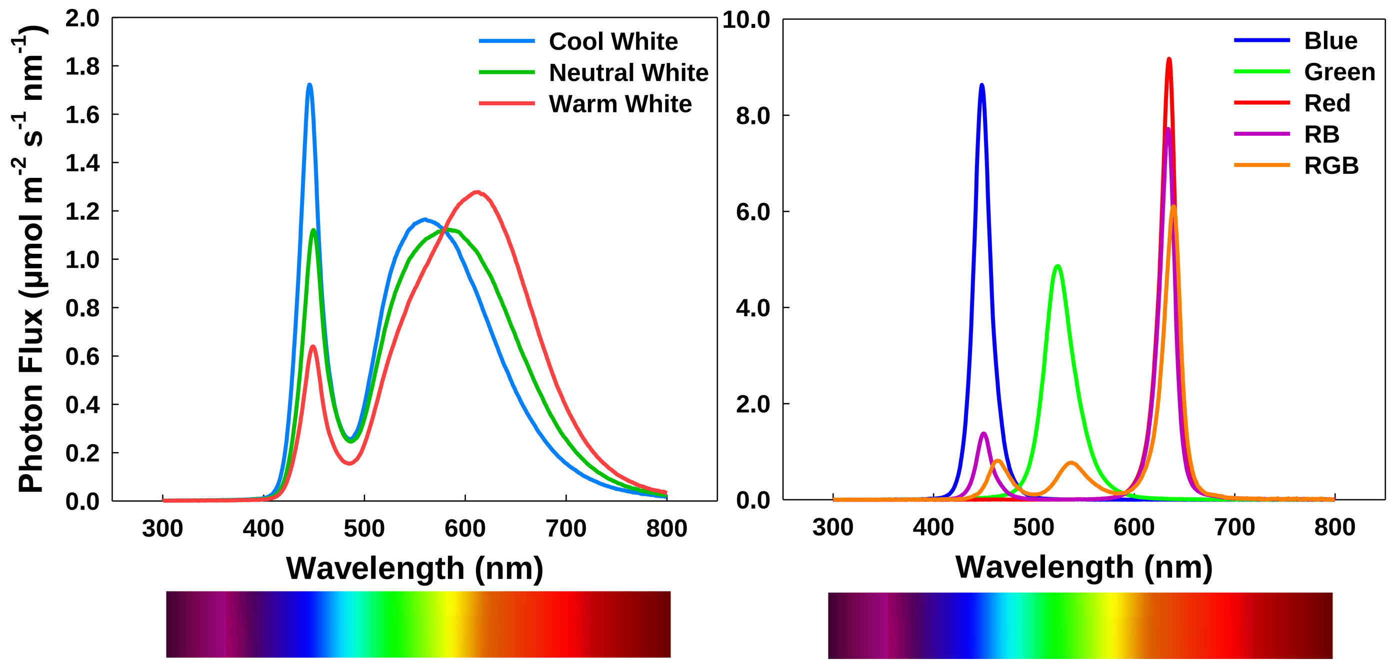

Figure 3. *Spectral traces for all eight LED treatments used for the experiment.*

Table 1. *Light quality parameters for the LED treatments used in this experiment.*

Light Quality Parameter	LED Type							
	Cool	Neut	Warm	Red	Green	Blue	RB	RGB
PPF =	500	500	500	500	500	500	500	500
YPF =	429	441	455	486	390	351	469	447
YPF/PPF =	0.86	0.88	0.91	0.97	0.78	0.70	0.94	0.89
% UV-A =	0.17	0.13	0.09	0.03	0.17	0.18	0.01	0.11
% Blue =	27.5	19.4	10.8	0.27	6.52	92.0	12.0	13.7
% Green =	37.8	34.5	29.0	0.39	91.1	7.77	0.71	21.6
% Yellow =	10.2	11.1	12.0	1.27	1.44	0.06	0.98	1.28
% Red =	24.5	35.0	48.3	98.1	0.96	0.22	86.3	63.4
PPE =	0.83	0.84	0.84	0.89	0.83	0.58	0.89	0.89
R/FR =	6.44	5.67	5.02	>999	0.4/0	0.1/0	>999	170.0/0

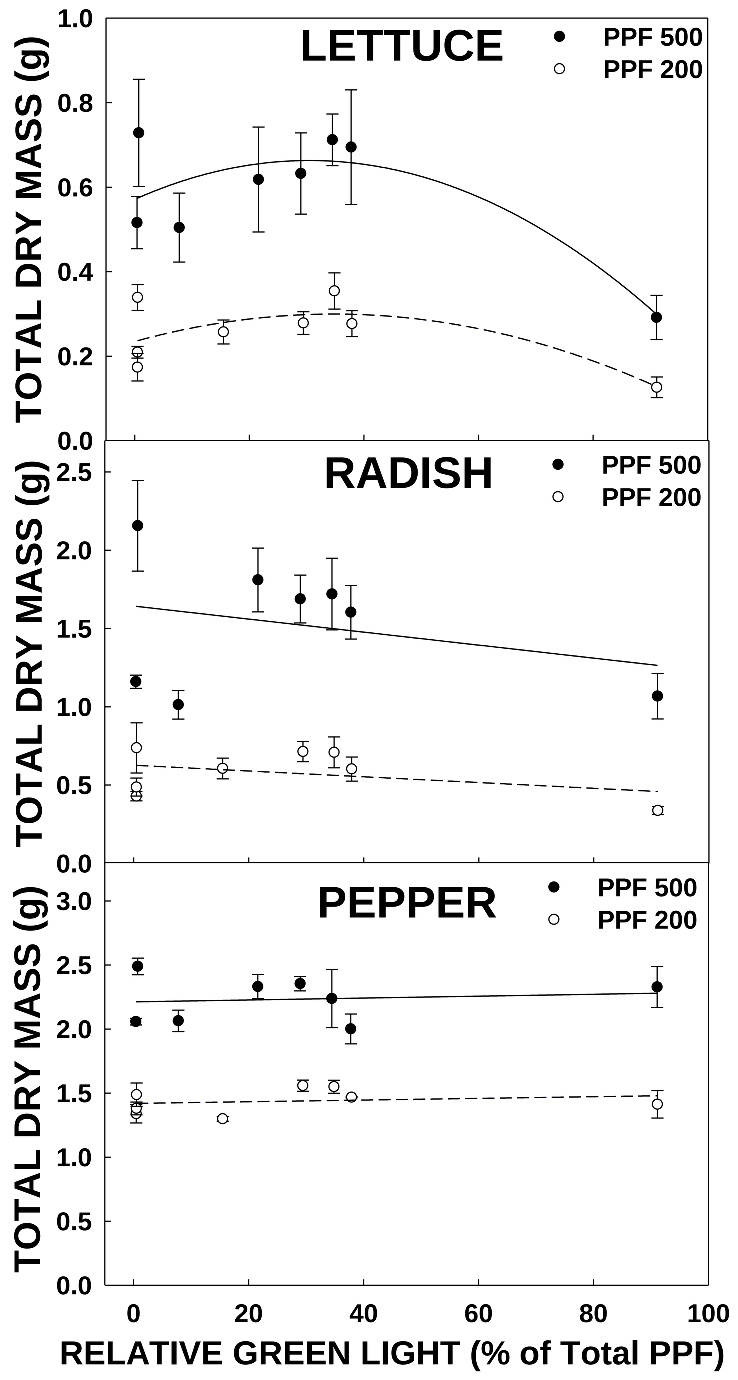

Figure 4. *The effect of green light on dry mass gain for lettuce, radish and pepper grown at 200 and 500 µmol m^{-2} s^{-1}.*

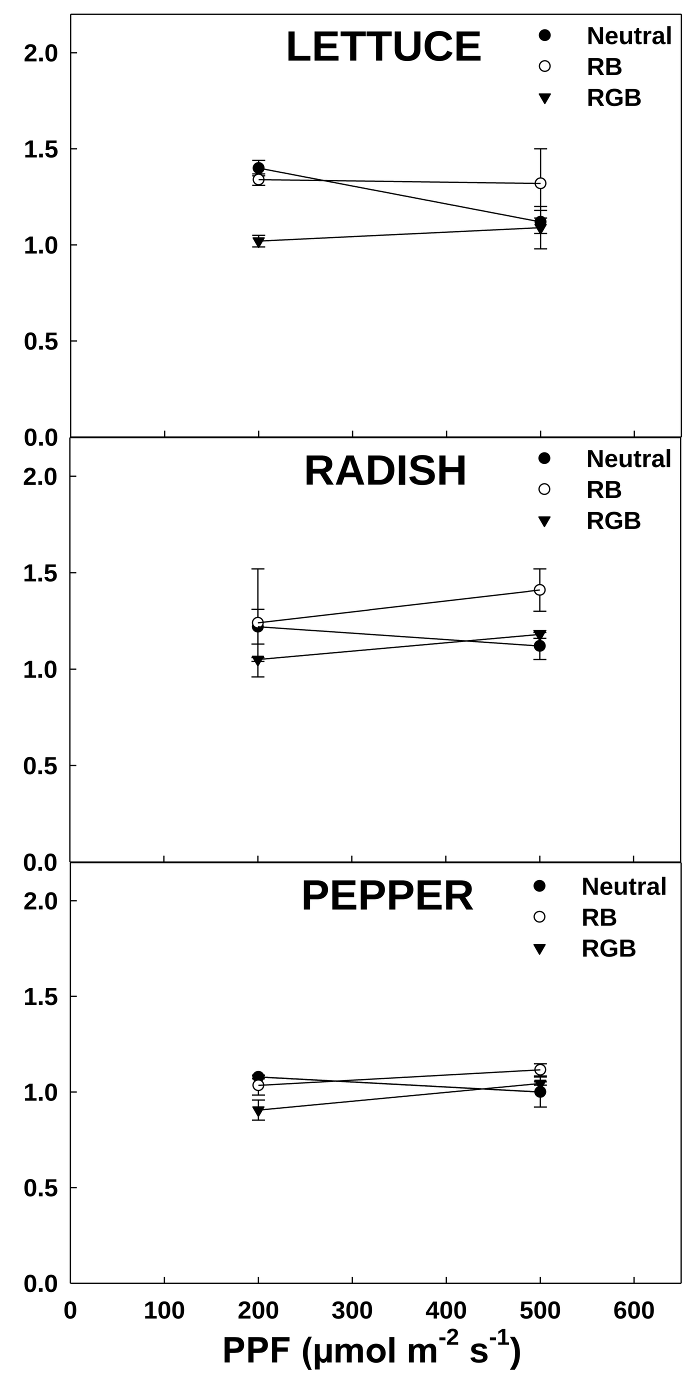

Figure 5. *Normalized dry mass gain in three broad-spectrum LED treatments plotted against photosynthetic photon flux (PPF).*

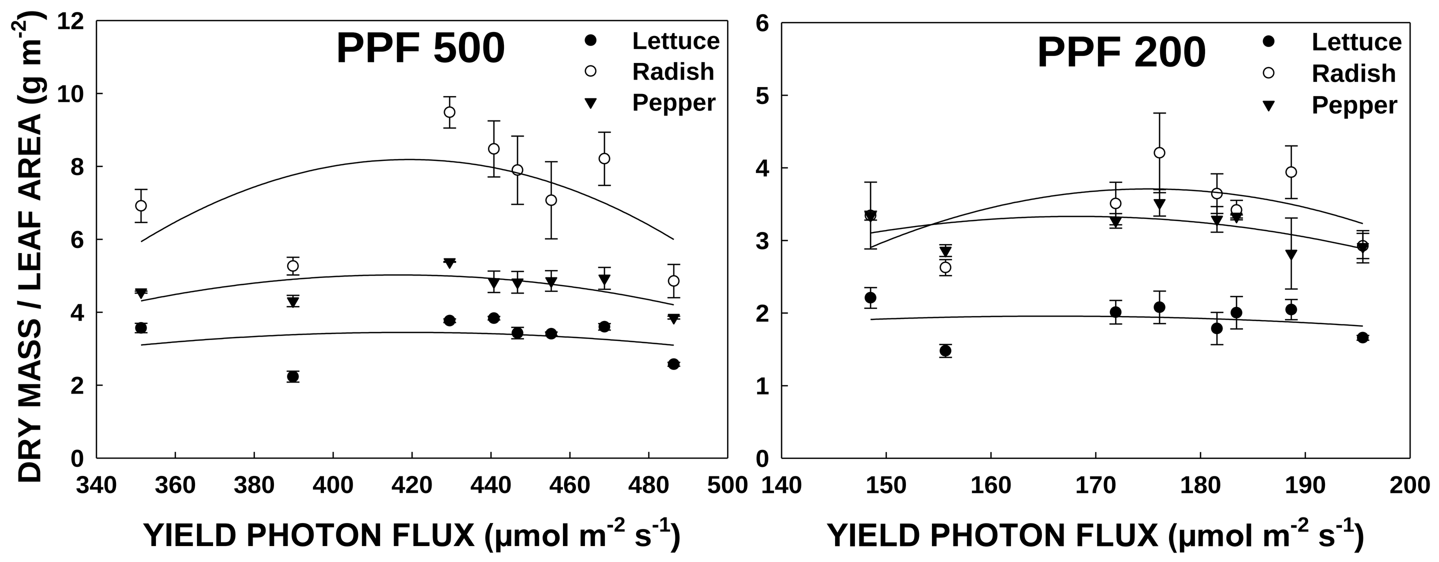

Figure 6. *Total dry mass gain per total leaf area for lettuce, radish and pepper grown at 200 and 500 µmol m^{-2} s^{-1} plotted against the yield photon flux (YPF) for each treatment.*

There was no effect of YPF on an estimated value for photosynthetic efficiency (PE; total DM gain per total LA) (Figure 6), indicating that YPF indeed only predicts the theoretical PE of a given light source without considering the effects that that light source will have on plant development. DM gain per LA should increase with increasing YPF; yet, the red LED treatment which had the highest YPF often had the lowest PE.

CONCLUSIONS

Our results suggest that growth responses to supplemental green light are likely species dependent. For affected species, clearly, there is an interaction between PPF and light quality, meaning that the value of supplemental green light decreases as PPF increases. Furthermore, excessive supplemental green light levels may induce partial shade-avoidance responses. Our current experiments are evaluating the value of green light after canopy closure when multiple leaf layers form. We expect that the value of green light will increase as this occurs.

ACKNOWLEDGEMENTS

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