Managing the Daily Light Integral for SPECIALTY Leafy Greens

Effective light management is critical for efficient crop production.

BY CHRISTOPHER J. CURREY AND JEAN YOST

The increasing popularity of specialty leafy greens such arugula (*Eruca sativa*), kale (*Brassica oleracea*), pac choi (*Brassica rapa* var. *chinensis*) and Swiss chard (*Beta vulgaris*) is causing more growers to produce them. However, as less-than-common species are produced in hydroponic systems and controlled environments, growers may be left without research-based recommendations. While several factors affect crop growth and development in controlled environment agriculture, the quantity of photosynthetic light plants receive on a daily basis (daily light integral; DLI). Whether in a greenhouse or completely indoor, effective light management is important for efficient crop production. Our objectives were to: 1) quantify the growth responses of arugula, kale, pac choi and Swiss chard to a range of DLIs; and 2) classify the DLI response for each species.

THE EXPERIMENT

Arugula, 'Starbor' kale, 'Win-Win' pac choi and 'Fordhook Giant' swiss chard were sown in 162-cell phenolic foam propagation sheets with a top groove (Oasis HortiCubes XL; Smithers-Oasis) placed in 1,020 flats with drainage holes. Immediately after seeding and every day throughout the experiment, flats were irrigated 100-ppm nitrogen (N) from a complete, balanced, water-soluble hydroponic fertilizer (Jack's Hydro FeED 16N-4P-17K; J.R. Peters). Seedlings were grown inside an environmental growth chamber at a constant air temperature of 72° F and a 16-hour day with a photosynthetic daily light integral (DLI) of 14 $mol \cdot m^{-2} \cdot d^{-1}$.

Two weeks after sowing seed, seedlings were transplanted into one of six 3-foot-wide, 6-foot-long, and 6-inch-deep deep-water culture (DWC) systems or "raft" systems. Each DWC system had a target EC of 2.0 and pH of 5.8 that was maintained with dosing systems fed with stock solutions of concentrated water-soluble fertilizer and potassium hydroxide stock solutions.

To create the different DLIs for the different treatment, we relied on three things: 1) variation in ambient (natural) light across seasons, 2) high-pressure sodium (HPS) lighting, and 3) spectrum-neutral shade cloth. First, we repeated our experiment numerous times over the course of the year, from late summer when the outdoor DLI is high, into the seasonally low DLI of the winter, into late spring when the DLI increases again. Secondly, we operated HPS lights in the greenhouse from 6 a.m. to 10 p.m., with lights turned off in the middle of the day. This allowed us to achieve DLIs greater than what we could have without lighting, as well as maintaining a consistent 16-hour day length for the different repetitions. Finally, a PVC frame was constructed around each individual hydroponic system, over which different shade cloths ranging from 25 to 50% light reduction, and additional layers of shade were used to achieve very low DLIs. Throughout the experiment, we were able to achieve DLIs ranging from 2 to 22 $mol \cdot m^{-2} \cdot d^{-1}$.

Data were collected two (arugula), three (pac choi) or four (Swiss chard and kale) weeks after transplanting into hydroponic systems and

Figure 1. This experiment used seasonal variation in sunlight, shade cloth and supplemental lighting (not shown in this photo) to create 16-hour days ranging in DLI from ~2 to 22 mol·m⁻²·d⁻¹.

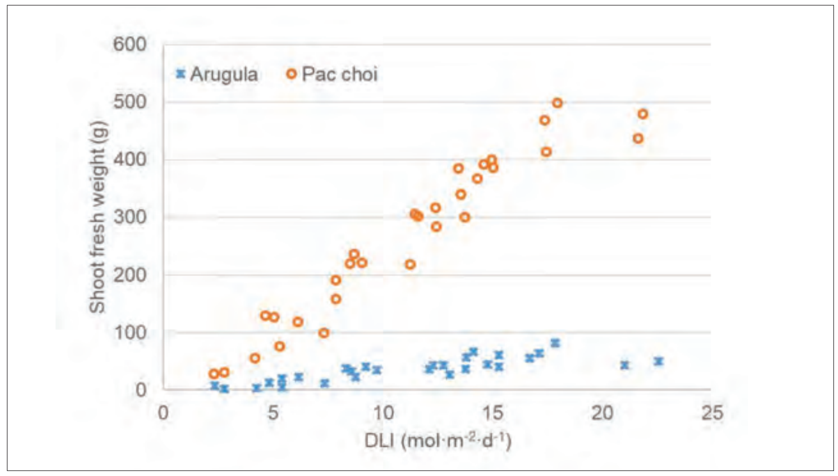

Figure 2. Fresh shoot weight of arugula and pac choi grown in daily light integrals ranging from ~2 to 22 mol·m⁻²·d⁻¹. Although shoot fresh mass increased for all species in this study, the magnitude of growth promotion varied between species, as seen here with arugula and pac choi.

DLI treatments. Prior to destructively harvesting plants, data were collected on chlorophyll fluorescence (a measure of plant stress), plant height and width, and leaf number and area. Plants were then removed from systems, the shoot was severed from the phenolic foam cube, and shoot fresh weight was recorded. After this, the leaves were separated from the stem, and leaves, stems, and roots were all individually bagged, dried, and weighed three days later.

THE RESULTS

For all four specialty leafy green species, increasing DLI from ~2 to 22 mol·m⁻²·d⁻¹ increased plant height and width. While this clearly reflects the growth-promoting effect of photosynthetic light, the height and width of food crops is much less important than compared to containerized ornamental plants, where plant size is a crucial determinant of quality. Although pac choi was unaffected, the leaf number of arugula, kale and Swiss chard also increased by one or two leaves per plant as DLI increased from 2 to 22 mol·m⁻²·d⁻¹. We attribute this increase not to the DLI or photosynthetic light directly, but to a slight increase in the leaf temperature as a result of the thermal radiation under the higher DLI treatments.

As the DLI increased the fresh weight of shoots increased for all four species. For kale, pac choi and Swiss chard, the response was linear; as DLI increased, fresh weight increased. For arugula, the fresh weight increased as DLI increased from ~2 to 18 mol·m⁻²·d⁻¹; however, at DLIs above 20 mol·m⁻²·d⁻¹, shoot fresh weight started to decline slightly. When weighed separately, the root, stem and leaf dry weight all increased in a similar manner to shoot fresh weight for the different specialty greens. However, although the fresh weight of leaves, stems and roots all increased with DLI, the changes were not proportional to one another; the increases were greater for shoots (leaves and stem) than for roots. This is fortunate for hydroponic food crop producers, as the additional light had a greater positive impact on the portion of the crop that is harvested and sold, as opposed to the root system. In turn, this improves the efficiency of inputs to increase the DLI, such as providing supplemental lighting.

Visible signs of stress, such as diminished plant growth (size, weight, etc.), may not always be apparent when some plants are experiencing light stress. We only saw slightly diminished growth with arugula grown at DLIs over 20 mol·m⁻²·d⁻¹. However, chlorophyll fluorescence can reveal plant stress that may be otherwise unnoticeable. Even when grown at the high end of DLIs in our study (i.e. 18 to 22 mol·m⁻²·d⁻¹), kale, pac choi and Swiss chard had fluorescence values that indicated healthy, non-stressed plants.

MANAGING DLI

This research shows the beneficial effects of increasing DLI on specialty green growth and productivity. In greenhouses, the effect of DLI is most apparent in the late fall, winter and early spring, when the seasonal ambient outdoor light is at seasonally low levels and yields are reduced or time to harvestable size is appreciably delayed. By understanding crop requirements and the effect of DLI on growth, producers can make informed lighting decisions.

Classifying crops by their lighting requirements based on growth responses of arugula, kale, pac choi and Swiss chard is useful in simplifying light management for greenhouse and CEA food crops. Across the range of DLIs in our research (~2 to 22 mol·m⁻²·d⁻¹), we found no saturation in growth responses to DLI for kale, pac choi, or Swiss chard. As such these plants can be classified as high (20 to 30 mol·m⁻²·d⁻1) or very high light (>30 mol·m⁻²·d⁻¹) plants. While research at DLIs above those used in this experiment would be useful to more accurately characterize these species, providing supplemental light in a greenhouse or increasing lighting in a vertical farm to that degree is not practical or, likely, economical. For arugula, the fresh weight diminished with DLIs over 20 mol·m⁻²·d⁻¹, resulting in a medium light (10 to 20 mol·m⁻²·d⁻¹) classification.

Finally, while increasing light enhanced growth of these specialty greens, the increases in fresh mass varied among the different species, when adjusted for the different crop times (i.e. two weeks versus four weeks). The increase in pac choi fresh weight was approximately 10-times the increase seen for arugula. Whether adding supplemental light in a greenhouse or increasing lighting in a vertical farm, consider the return on investment, with respect to yield improvements. Additional lighting should be preferentially given to those crops that will give you the greatest return on the additional input (and cost).

TAKE HOME

Photosynthetic light has a large influence on hydroponic and controlled-environment crop growth. However, increasing light to promote growth also needs to be economically justifiable. Whether in an indoor farm or in a greenhouse, our results can be used to make more informed light management decisions for arugula, kale, pac choi and Swiss chard.

Christopher Currey (ccurrey@iastate.edu) is an associate professor and Jean Yost is a graduate research assistant in the Department of Horticulture at Iowa State University.