e-GRO Alert

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Volume 8 Number 25 May 2019

Producing Robust Plugs – Part III

Growing high-quality plugs is central to producing top-notch, seed-propagated bedding plants. Monitor and manage light in the greenhouse to produce robust, appropriately sized plugs.

Mother's Day is only two days away and retail-ready bedding plants have filled benches and racks with color all over the US. Though commercial propagators are already preparing for chrysanthemum and poinsettia season, many growers who produce plugs in-house are looking at their finished bedding plants and thinking about how they can improve on next year's crop. For seed-propagated bedding plants, improving quality fundamentally starts in the plug phase.

Over the past few weeks, I have seen bedding plants in retail outlets and on grower visits that are leggy, slow-growing, and have low flowering vigor post-transplant (Fig. 1). These symptoms can often be traced back to insufficient light levels during plug production. In previous Alerts this season, I covered management of crop-cultural factors such as substrate moisture (e-Gro Alert 8.17), and water quality/mineral nutrients (e-Gro Alert 8.21) in bedding-plant plug production. In this Alert, we will cover light management considerations for maximizing plug growth and quality.

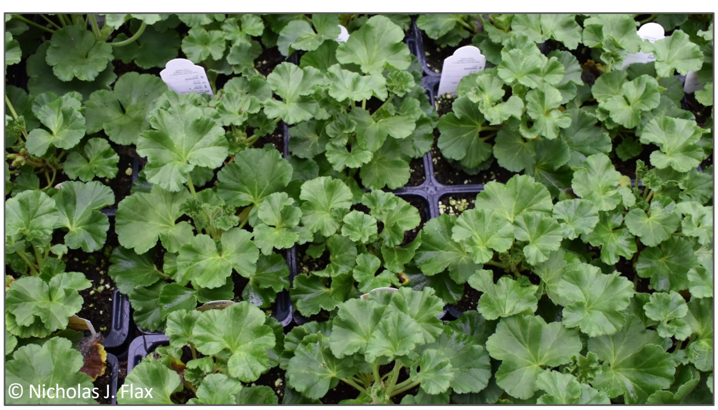
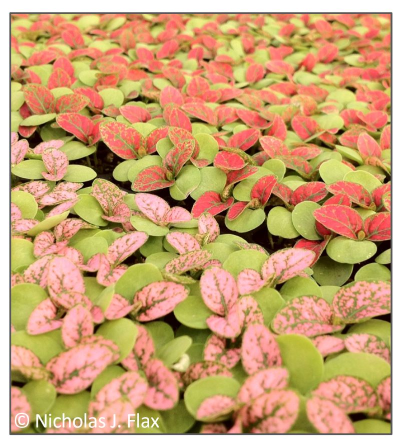


Figure 1. These seed-propagated zonal geraniums (*Pelargonium × hortorum*) were scheduled to finish by Week 18. This was the first year that this grower produced their plugs in-house and, though water and mineral nutrients were managed properly, plugs took longer to grow than expected, and were slow to establish or flower after transplant. Low light during plug production is likely the source of these delays.



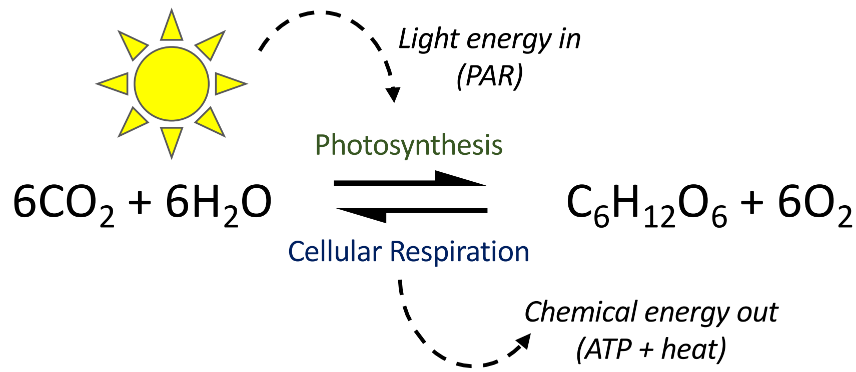


Figure 2. Photosynthesis is the fundamental process that drives plant growth. During photosynthesis, plants use photosynthetically active radiation (PAR) to combine carbon dioxide (CO_2) and water (H_2O) molecules and create carbohydrates ($C_6H_{12}O_6$). These carbohydrates are broken apart by the plant as needed, and the energy stored within is used to power various metabolic processes that are essential to plant growth.

Physiology Review. When managing environmental parameters such as light, it is important to remember the role that it plays in plant physiology. On the most fundamental level, light controls plant growth. Plants harness the power of photosynthetically active radiation (PAR; light energy in the 400–700 nm waveband) to create carbohydrates or "sugars" using carbon dioxide from the air and water (photosynthesis; Fig. 2). These carbohydrates are then used to power different metabolic processes that are essential to plant growth. **A plant can only grow as much as it can photosynthesize, so ensuring that an adequate amount of PAR is provided to young, rapidly developing plugs is essential.**

Quantifying PAR. In crop production, quantities of PAR are looked at in two primary ways:

$mol{\cdot}m^{-2}{\cdot}d^{-1}$ – "Moles of light photons per square meter per day" is the unit used to express total PAR accumulated over a 24-hour period. This is often referred to as daily light integral (DLI).

$\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ – "Micro-moles of light photons per square meter per second" is the unit used to express PAR intensity (amount of light photons raining down) in a given moment. This is referred to as instantaneous light intensity.

1 mol = ~6.02×10^{23} (very large number) & 1 µmol = ~6.02×10^{17} (1,000,000th of 1 mol)

To put these terms into context, think of PAR units like measures of rainfall. For example, during a storm, rainfall may fluctuate between periods of light and heavy precipitation. Similarly, instantaneous light intensity ($\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$) fluctuates at crop-height as clouds pass in front of the sun or different parts of a greenhouse's superstructure block light as the sun's angle changes. On the other hand, DLI ($mol{\cdot}m^{-2}{\cdot}d^{-1}$) is effectively a "rain gauge for PAR". Though instantaneous light intensity varies throughout the day like rainfall during a storm, light energy is accumulated by plants over time similarly to precipitation in a rain gauge. The total amount of PAR "collected" by a plant in 24 hours is largely unaffected by changes in light intensity, just as water collected in a rain gauge measures total precipitation regardless of differences in rainfall rates during a storm. This is part of what makes DLI such a robust metric to examine in the context of plant growth.

Quantifying PAR cont. Ultimately, plant growth is more a function of accumulated light energy than light intensity at any given moment in time. Experienced growers may be able to approximate light levels in a greenhouse by sight, but instantaneous light and DLI can only be monitored accurately using a quantum sensor (Fig. 3). If not monitored and managed regularly, too much or too little light can negatively impact plant growth. **As such, when growing a large number of seedlings in close proximity to one another, monitoring and managing PAR to appropriate levels is critical in order to maximize plug growth and quality.**

Managing Light Levels. Plugs go through multiple growth and developmental phases from sow to finish, and light should be managed according to plant needs during the different plug stages (Fig. 4–7). Table 1 (pg. 6) contains general light-management considerations for plug Stages 1–4 (germ. and radicle emergence to plug toning, respectively).

PAR, or lack thereof, is generally the most limiting plant-growth factor when producing plugs. Having the ability to attain an average DLI of ~10 $mol \cdot m^{-2} \cdot d^{-1}$ during production most times of the year ideal. If you are unsure of what the average DLI is in your greenhouse and a quantum sensor is not available, growers in the US can use this [interactive DLI map] (developed by Jim Faust, Clemson University and Joanne Logan, University of Tennessee) to get an estimate. This map shows average outdoor DLI on a month-by-month basis. However, most greenhouses only allow ~40–60% of outside light to reach crop height. Dividing the average DLI for your location by two (2) will provide a rough estimate of PAR levels in your greenhouse during any given month.

Figure 3. Data loggers equipped quantum sensors can monitor and record average instantaneous light intensity and daily light integral (DLI). Certain hand-held meters can be used in a similar manner, and many greenhouse environment controllers have integrated PAR sensors to track light in multiples bays at once.

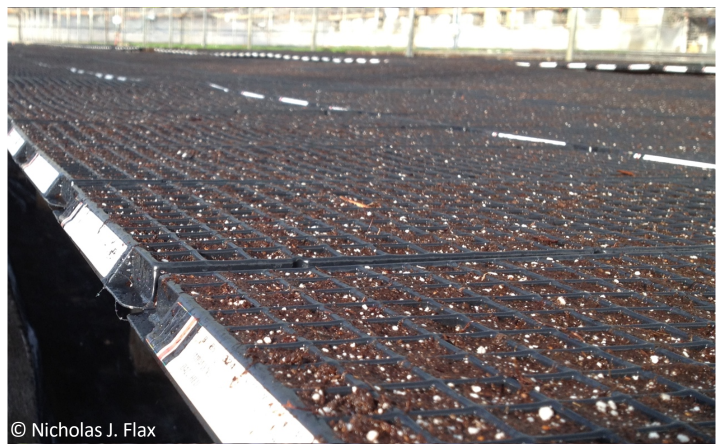


Figure 4. Plug Stage 1 (germination and radicle emergence) can take place in a dark germination chamber or on a greenhouse bench. Seeds of wax begonia (*Begonia semperflorens-cultorum*), for example, need light to germinate. Ambient light is often sufficient to satisfy germination requirements.

Figure 5. Seedling plugs in Stage 2 (cotyledon expansion) are sensitive to low light levels. If growing conditions are too dark, hypocotyl stretch may occur. These Stage 2 (almost Stage 3; true-leaf expansion), 288-cell petunias (*Petunia* × *hybrida*) may begin to stretch if light intensity is not increased.

Figure 6. These 288-cell coleus (*Solenostemon scutellaroides*) seedlings have recently entered Stage 3 (true-leaf expansion). This grower moved these seedlings into a bay with supplemental lighting to help keep plugs compact and encourage new leaf growth, as well as roots.

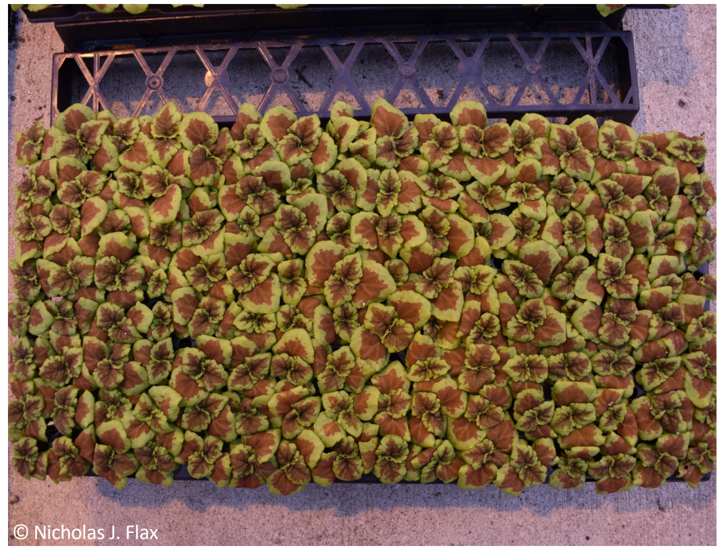


Figure 7. Now at the tail-end of Stage 4 (toning), these coleus (*Solenostemon scutellaroides*) seedlings are ready to be transplanted. This grower ensured that light levels increased steadily from sow to finish and remained within optimal ranges to encourage robust shoot and root growth, and compact habit.

Managing Light Levels cont. Growers at more-southern latitudes and higher altitudes are often well-suited to growing plugs in January–March due to naturally higher average DLI in their geographical regions. At northern latitudes, average ambient DLI during the traditional plug production season is not sufficient for growing bedding-plant seedlings. In regions where natural light levels are low from January through early March, commercial plug growers often use an extensive amount of supplemental lighting (Fig. 8). High-intensity discharge fixtures with high-pressure sodium (HPS) lamps or light-emitting diode (LED) fixtures are currently the most commonly used types of supplemental light sources. However, this solution is often not feasible for smaller and mid-sized growers.

If you are not a commercial plug grower but predominately produce bedding-plant seedlings in-house, providing a minimum DLI of 5–10 $mol \cdot m^{-2} \cdot d^{-1}$ is essential. Below this range, plug growth will be very slow and seedling quality will be poor. If your greenhouse light levels are below an

Figure 8. Natural light levels from January through early March often yield sub-optimal greenhouse light levels for seedling plug production in the northern US. In order to deliver a sufficient amount of photosynthetically active radiation (PAR) to plugs, many commercial propagators in northern states install a large number of supplemental lighting fixtures. The economics of high dollar-per-square-foot crop values commanded by plugs and relatively short cropping cycles often support the extensive investment in supplemental lighting. Here, supplemental PAR is provided by high-pressure sodium lamps. Other propagators install light-emitting diode (LED) fixtures as their supplemental PAR source.

Figure 9. Even in a polyethylene film-covered Quonset house with limited superstructure, supplemental lighting fixtures can be installed. Passively cooled light-emitting diode (LED) fixtures like this one can be installed with minimal hardware or risk of melting nearby glazing material, as they give off very little heat compared to other high-intensity discharge fixtures (ex. high-pressure sodium lamps).

Figure 10. These larkspur (*Consolida ajacis*) seedlings remained in their germination chamber too long after radicle emergence (Stage 1). Low light levels in the chamber encouraged hypocotyl stretch as a result. Monitor plug trays in germination chambers closely and move them into the greenhouse promptly after germination to avoid this issue.

Managing Light Levels cont. average DLI of 5 $mol \cdot m^{-2} \cdot d^{-1}$ during typical plug season, consider investing in a few supplemental lighting fixtures for your propagation area (Fig. 9) and grow only more-problematic plug crops under lights. When growing bedding-plant seedlings, also keep in mind that weathered glazing materials will reduce ambient light levels in the greenhouse. Attempting to get a few more years out of your polyethylene film or polycarbonate may end up costing you more in the long-run if plug (and subsequently, finished-crop) quality is compromised. If you want to grow more plugs in-house, but installing supplemental lighting is not possible due to limited electrical service or greenhouse structural constraints, you may want to consider building a separate plug greenhouse. If finances are the limiting factor, it may be worth purchasing plugs from a commercial propagator rather than struggling with the challenges of growing plugs under poorly lit conditions.

Summary. Light is the primary force that drives plant growth. Providing appropriate amounts of PAR to young, rapidly growing seedlings during different plug growth stages (1–4) is essential to encourage robust growth and maintain a compact habit. Mismanaged light levels, especially during Stages 1 and 2, can be detrimental to plug quality. Monitor light intensity and DLI using a quantum sensor, and take corrective action when light reaches sub- or super-optimal levels. If growing plugs at northern latitudes, consider adding supplemental lighting fixtures to maximize seedling quality. If installing supplemental lighting is financially impossible or physically impractical, consider buying your bedding plant plugs from a commercial propagator.

Table 1. Though annual bedding plants have crop-specific optima for light, general symptoms often present when light reaches sub- or super-optimal conditions. Instantaneous light intensity and daily light integral (DLI) values provided here are general ranges for good growth at different plug stages. Always consult production guides and technical data provided by plant breeders for crop optima.

Note: Historically, growers in the US are familiar with discussing light intensity in foot-candles (f.c.) and not $\mu mol \cdot m^{-2} \cdot s^{-1}$ of photosynthetically active radiation (PAR) or DLI. To help facilitate a better understanding of what appropriate light intensity ranges look like for plug production, instantaneous light values provided are based on average light intensity of PAR required to achieve each respective DLI under an 11-hour photoperiod (approximate daylength in mid-February, during peak plug-production season).

Plug Stage	Light Level	Management Considerations
Stage 1 (germination & radicle emergence)	Too low ↓	Some plant taxa require light for germination to occur. If using a germination chamber, provide at least 2–5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of light from electrical lighting fixtures (fluorescent most common). If germinating seeds on a greenhouse bench, low-intensity sunlight will likely be sufficient.
	Too high ↑	Inhibition of germination due to high light is rare, but excessive light hitting a newly germinated seed could damage the radicle or increase the risk of desiccation – especially if seeds are uncovered. If germinating on a greenhouse bench, maintain substrate moisture at a level where rapid dry-down is unlikely, especially high under higher-light conditions.
Stage 2 (cotyledon expansion)	Too low ↓	Seedling hypocotyls may stretch if insufficient light is provided post-germination, resulting in tall or floppy plugs. This often causes down-stream production challenges, particularly during transplant. Monitor newly seeded plug trays and remove from germination chambers promptly upon radicle emergence. To curb hypocotyl stretch, target instantaneous light levels of ~125–175 $\mu mol \cdot m^{-2} \cdot s^{-1}$ to achieve a target a DLI of ~5–7 $mol \cdot m^{-2} \cdot d^{-1}$.
	Too high ↑	Seedlings may become stunted and photo-bleaching of the cotyledon may occur; plants may terminate if too severe. To prevent, reduce light levels by pulling shade cloth or shorten operating time of supplemental lighting.
Stage 3 (true-leaf expansion)	Too low ↓	True-leaves will grow slowly and overall growth will be sparse; compact habit will be difficult to maintain. Poor root development may also occur. Encourage robust shoot and root growth by increasing instantaneous light to ~175–250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ to achieve a target a DLI of ~7–10 $mol \cdot m^{-2} \cdot d^{-1}$.
	Too high ↑	Stunting or leaf margin necrosis can occur on younger true-leaves. Photo-bleaching may occur on young leaves of shade-loving annuals. Reduce light levels via shade curtains or shortening operation time of supplemental lighting.
Stage 4 (toning)	Too low ↓	Similar shoot and root growth concerns to Stage 3. Low light during toning may cause seedlings to become soft, or flower more slowly/produce fewer flowers after transplant than plugs grown under high-light conditions. Increase instantaneous light to ~250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ or higher and target a DLI of 10 $mol \cdot m^{-2} \cdot d^{-1}$ or more. Restrict shading unless curtains are being pulled to reduce greenhouse air temperature.
	Too high ↑	Damage from high light is rare. Light intensity required to damage plugs in toning stage would likely impact plants more via increasing air temperature to super-optimal levels. Restrict shading unless curtains are being pulled to manage greenhouse air temperature.

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