FIRST Research Report

Light Management in Greenhouses

II. Plant Growth Responses to Daily Light Integrals.

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The amount of light that a plant receives has a tremendous impact on plant quality and marketability. Plants can be thought of a “light counters”, in other words, they count the number of particles of light that they are able to absorb. The intercepted light then fuels photosynthesis and growth. This is the beauty of using Daily Light Integrals (DLI) to describe the greenhouse light environment, since it is a direct measure of the number of particles of light delivered to the plant; therefore, plant growth is closely correlated with DLI.

The purpose of this project was to identify how plants respond to DLI so that growers can more efficiently utilize the light delivered to their greenhouse.

Measuring Plant Growth

Growth can be measured in several ways. One of the simplest measures of growth is fresh weight, which is simply the weight of the growing tissues (roots, shoots, and flowers). Dry weight is the weight of the same tissue minus the water (the water is removed by placing the plant tissue in the oven). Growers don’t sell bedding plants based on their weight, but this is still a reasonable method for describing growth. Additionally, we like to divide the shoot fresh or dry weight by the height of the plant. This provides the weight per unit height, which a good indicator of plant quality, since the higher the weight per inch of height, the “fuller” the plant, and plant quality is closely associated with the “fullness”. Growth can also be quantified by measuring the number of lateral stems, stem diameter, leaf size (area), flower size (diameter), and flower number.

Our results will be presented as a general series of principles that growers will benefit from understanding. Then, we will follow with a discussion of more specific responses to DLI.

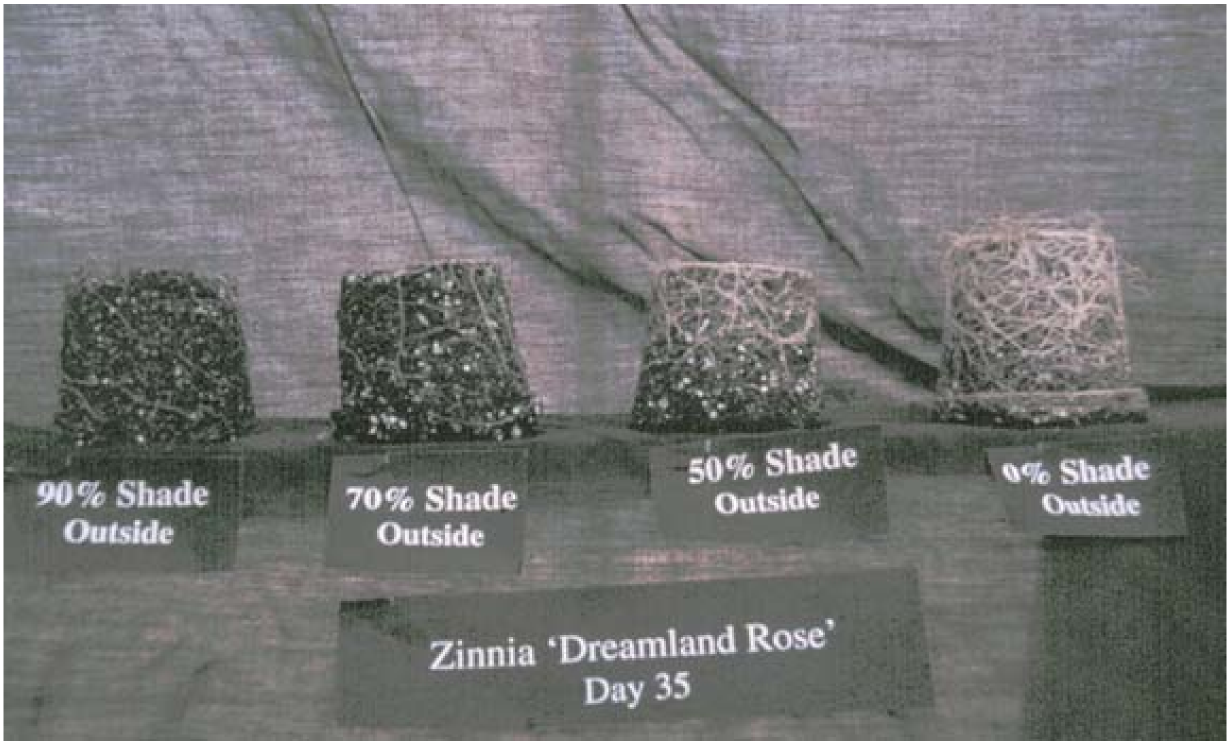
1. Plants partition their resources to the area of greatest need

Under low light conditions, plants try to increase light interception. The best way to do this is by increasing the area of individual leaves. These leaves tend to be very thin and pliable. In contrast, individual leaf size decreases and leaf thickness increases under high light conditions. These leaves are thick and have accumulated a lot of starch. However, under high light conditions, plants will have more leaves. So, even though they are individually smaller leaves, the leaf area of the entire plant increases as DLI increases.

2. Root growth is proportional to shoot growth

Roots are dependent on shoots (leaves and stems) for sugars created during photosynthesis, while shoots are dependent on roots for water and nutrients. So, it should come to no surprise that root and shoot growth are proportional. Shoot growth increases as DLI increases, so root growth also increases as DLI increases. Although this may be common sense, it can be surprising to observe how root growth dramatically increases as DLI increases (Figure 1).

Figure 1. The effect of daily light integral on zinnia root growth. The plants received (*left to right*) 4, 14, 24, and 48 moles/day.



3. Many "shade" crops grow best under moderate to high light levels

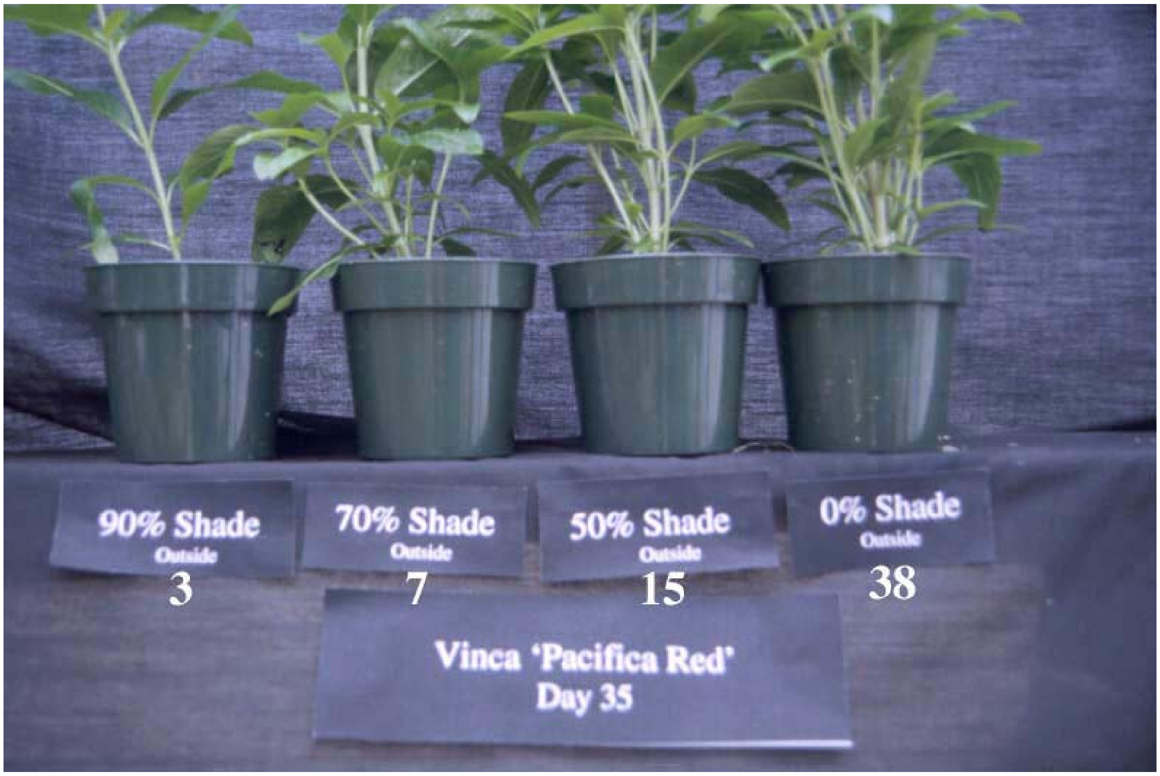
It is probably best to describe shade plants as those species that "tolerate" low light conditions; however, many of these species actually grow best in moderate to high light conditions. For example, begonias produce commercially accepted plants under low DLI conditions (5 moles/day), but the highest quality begonias are produced at a much higher DLI (~20 moles/day). Keep in mind that although the best growth, in terms of plant size, may occur at higher light levels, the leaves may be more attractive under moderate light levels.

Another example is Hosta. Many varieties of hosta grow best outdoors under full sun conditions; however, they require ample water. If drought stress occurs, sunburn will occur under full sunlight.

4. Increasing DLI increases branching

Under low light conditions, there may only be enough energy to support the primary stem. If the light levels increase, more lateral shoots will develop. In other words, the plant will only develop a lateral shoot if there is plenty of food (sugars from photosynthesis) to support those shoots. Therefore, the number of lateral branches increases as DLI increases (Figure 2).

Figure 2. The effect of daily light integral on vinca branching. The plants from left to right received 3, 7, 15, and 38 moles/day.



5. Large plants benefit more from higher DLI than small plants

Individual leaves do not require high light levels to saturate their ability to do photosynthesis. So, small plants do not require high light levels to achieve their maximum growth rate. ("Small" refers to total leaf area of the plant relative to the amount of space occupied by the plant. This is called the Leaf Area Index.). Larger plants benefit from higher light levels because the lower leaves are heavily shaded. Thus, relatively high light levels are required for the lower leaves to reach their full photosynthetic potential.

DLI=Growth=Quality

In most cases, the growth resulting from increasing DLI improves plant quality. More light = more lateral shoots = more flowers = a higher quality plant. The exception occurs with some "shade crops". For example, impatiens and begonia actually achieve more growth (fresh and dry weight, lateral shoots etc…) in full outdoor sunlight. However, the appearance is inferior, since the leave and flowers often have a faded or bleached appearance in full sun.

Maximizing versus Optimizing

In most cases, there is a "diminishing returns" effect on plant growth as DLI increases. For example, plants grown in a greenhouse may be 2X greater at 20 moles/day versus 10 moles/day; however, plant quality may be commercially acceptable at 10 moles/day. So, 20 moles/day may provide the maximum growth rate, while 10 moles/day is optimal, assuming the other 10 moles/day can be used to grow additional plants, e.g., hanging baskets.

DLI affects growth, Temperature affects timing.

Light and temperature responses are sometimes confused. Light has a large impact on growth, while temperature influences development. Growth refers to plant size, fresh mass, dry mass, branching and flower number. Development refers to leaves or flowers being developed in the meristematic areas of the plant. Thus temperature influence how fast leaves and flowers develop.

The interaction of temperature and light has a big impact on plant quality. The biggest and best quality plants are often grown under high light and cool temperatures. These conditions allow for a lot of energy (sunlight) to be packed into the plant, since the leaves are developing relatively slowly. In contrast, low light and high temperatures are the worst conditions for growing most plants. Under these conditions, very little energy is available, yet the plant is developing leaves and flowers very rapidly. The result is poor quality plant appearance. During summer conditions, growers must be careful not to create these conditions be providing excess shade during the hot summer months.

Low light does not = stretch

It is common perception amongst grower that low light conditions promote plant "stretch". Our data do not support this conclusion. In most situations, low DLI (<5 moles/day) produces shorter plants than moderate DLI environments (10 moles/day). Under low DLI condition, the plants lack sufficient energy to produce a vigorous primary shoot. In nature, no competitive advantage exists for a plant to grow taller after several cloudy days, since increased height will not result in increased light interception. So, why might we perceive that plants stretch under low light conditions. There are several possibilities:

1. The growth that occurs under low DLI is often very poor, thus, the poor quality growth is perceived as “stretch” since low light plants lack lateral branches and have thin stems and leaves (Figure 3)
2. It is possible that flower initiation and/or development is inhibited so that low light plants require more time to flower. As a result, they get taller prior to flowering because more leaves are formed on the stem prior to a flower initiating in the shoot tip.
3. Low light plants dry out slower than high light plants. It is possible that an amply-watered low light plant grows taller than a drought-stressed high light due to the higher humidity and the lack of drought stress.
4. Plants that have a prostrate or low-growing habit may elongate more under low light. In nature, it makes sense that a petunia or pansy would benefit from elongating if the stems and leaves were being shaded by debris, such as dead leaves, on the soil surface. For example, pansy petioles appear to elongate under low light conditions.

Figure 3. The effect of daily light integral on A) Vinca and B) Zinnia height and quality. Vinca received (*left to right*) 3, 7, 15, and 38 moles/day, while zinnia received 4, 14, 24, and 48 moles/day. Note that plant height, branching and flowering increased as DLI increased.

A.


90% Shade
Outside
3
70% Shade
Outside
7
50% Shade
Outside
15
0% Shade
Outside
38
Vinca 'Pacifica Red'
Day 35

B.

Spacing affects the DLI intercepted

If 20 moles/day of light is delivered to a 4” petunia spaciously grown at 8”x8” spacing and to a 4” petunia grown pot-to-pot (4”x4” spacing), the plant grown at wide spacing will likely intercept more light. Wide spacing allows more light to be absorbed by the sides and interior of the plant. Thus, a plant’s light requirement increases as it begins to be shaded by neighboring plants.

Categorizing Plant DLI Requirements

Plants can be categorized into very low light, low light, moderate light, high light, and very high light responses. Following is a generalization of plant responses to different light levels.

Very Low Light

Very low light conditions (<5 moles/day or 500 to 1000 footcandles), typically results in poor quality plant growth and flowering. Under very low light conditions, the plant lacks sufficient energy to produce a high quality plant. The plants often have just one thin primary stem with very little lateral branching. There may be insufficient light to support flowers, so flowering can be delayed, flowers may be very small, few flowers may be produced, or the plants may stay entirely vegetative, i.e., not produce any flowers. Supplemental lighting is very beneficial under these DLI conditions. Only a few crops, such as African violets, can produce acceptable plants under very low light conditions.

Low Light

The quality of the growth that occurs under low light conditions (5-10 moles/day or 1000 to 2000 footcandles), largely depends on the greenhouse temperatures. Under cool growing conditions (<65^{o}F), plant quality can be quite good. For example, northern European growers compensate for low light conditions by growing their crops cool. Crop time is increased but the quality is good. Cool temperatures allow the leaves and flowers to develop slowly which allows the plant more time to accumulate energy from sunlight to produce healthy leaves and flowers. In contrast, high temperatures (>75^{o}F) during low light conditions result in poor quality growth. Under warm temperatures, the plant is developing new leaves and flowers very quickly, but there is insufficient energy from sunlight to produce substantive leaves and flowers. Supplemental lighting is beneficial under these DLI conditions.

Moderate Light

Plant growth is usually commercially acceptable for most greenhouse crops grown under moderate light conditions (10 to 20 moles/day or 2000 to 4000 footcandles). Plants flower normally with acceptable branching and flower number. Most potted flowering plants perform very well under moderate light conditions. It is relatively easy to manage watering under moderate light conditions compared to higher light levels. Once the plant has sufficient light to support flowers, increasing the light level further has little effect on time to flower. The potential benefit of supplemental lighting is limited under moderate DLI conditions.

High Light

The highest quality greenhouse-grown bedding plants, stock plants, and herbaceous perennials are usually produced under high light conditions (20-30 moles/day or 4000-6000 footcandles). These crops often produce commercially acceptable crops at moderate light conditions; however, the quality will improve further under high light conditions. High light conditions provide extremely well-branched (bushy) plants and high flower numbers. Root growth is proportional to shoot growth, so high light conditions also produce excellent root systems. The highest yields of greenhouse-grown cut flower crops and greenhouse vegetables are typically grown under high light levels; however, excessive greenhouse temperatures can limit greenhouse yields even though higher light levels are desirable for these crops. As a result, greenhouse performance and yields of cutflower and vegetables are often less than what can be achieved with outdoor production.

Very High Light

Many species produce superior quality plants outdoors compared to inside greenhouses. This is due to higher light levels (30-60 moles/day or 6000 to 10000 footcandles) and cooler plant temperatures. Plant temperatures can be cooler outdoors due to increased air movement, lower relative humidity and thermal cooling due to the exposure to the open sky.

Plants considered shade plants may actually grow very well in full outdoor sunlight provided that ample water is available and temperatures do not become excessive. For example, many hosta varieties grow very well outdoors throughout the summer in the southeastern U.S. as long as the plants are well-watered. Large leaf varieties experience higher leaf temperatures under high light conditions, thus these plants may require shade to prevent sunburn.

Excessively high light may result in a change in leaf orientation and shape. Leaves grown under excessively high light produce a more vertical and curled leaf blade in order to avoid light interception. For example, the leaves of young pansy plants may curl when grown at 40 moles/day (outdoor summer light levels) even if temperatures are cool. Excessive light can also result in heat stress or "sunburn" of some species. Sunburn is most likely to occur when a plant has not been acclimated to high light conditions. Plant water use and evaporation increases as sunlight increases, so water management can be more difficult under high light conditions. Root death can also occur on the south side of dark-colored containers due to excessively high soil temperatures resulting from direct outdoor sunlight.

Table 1 provides a comparison of light requirements for various floriculture crops. Species differ in both the minimum and maximum acceptable light levels. The minimum and maximum ranges can be altered by temperature and water. Cool temperatures will allow plants to be grown at lower light levels, while the minimum light levels are higher at warm temperatures. Similarly, high temperatures can limit the amount of light that "cool" crops can absorb. For example, lobelia and fuchsia tolerate full sunlight if the temperatures are moderate, but require shade when temperatures are warmer. Water can also modify the light requirement. For example, caladiums are typically considered to be a shade crop, while they are grown outdoors in full sunlight in Florida for tuber production. However, ample water is always provided. Drought stress under full sunlight conditions is damaging to many species, since drought forces the stomata on the leaves to close. As a result, transpiration ceases and leaf temperatures begin to increase dramatically.

Table 1 differentiates between the light levels required for minimal acceptable quality, good quality and high quality crops. These are subjective categories, but the intent is to demonstrate that plant quality improves as the daily light integral increases.

Table 1. Generalized responses of various greenhouse crops to daily light integrals.

░ Fair quality

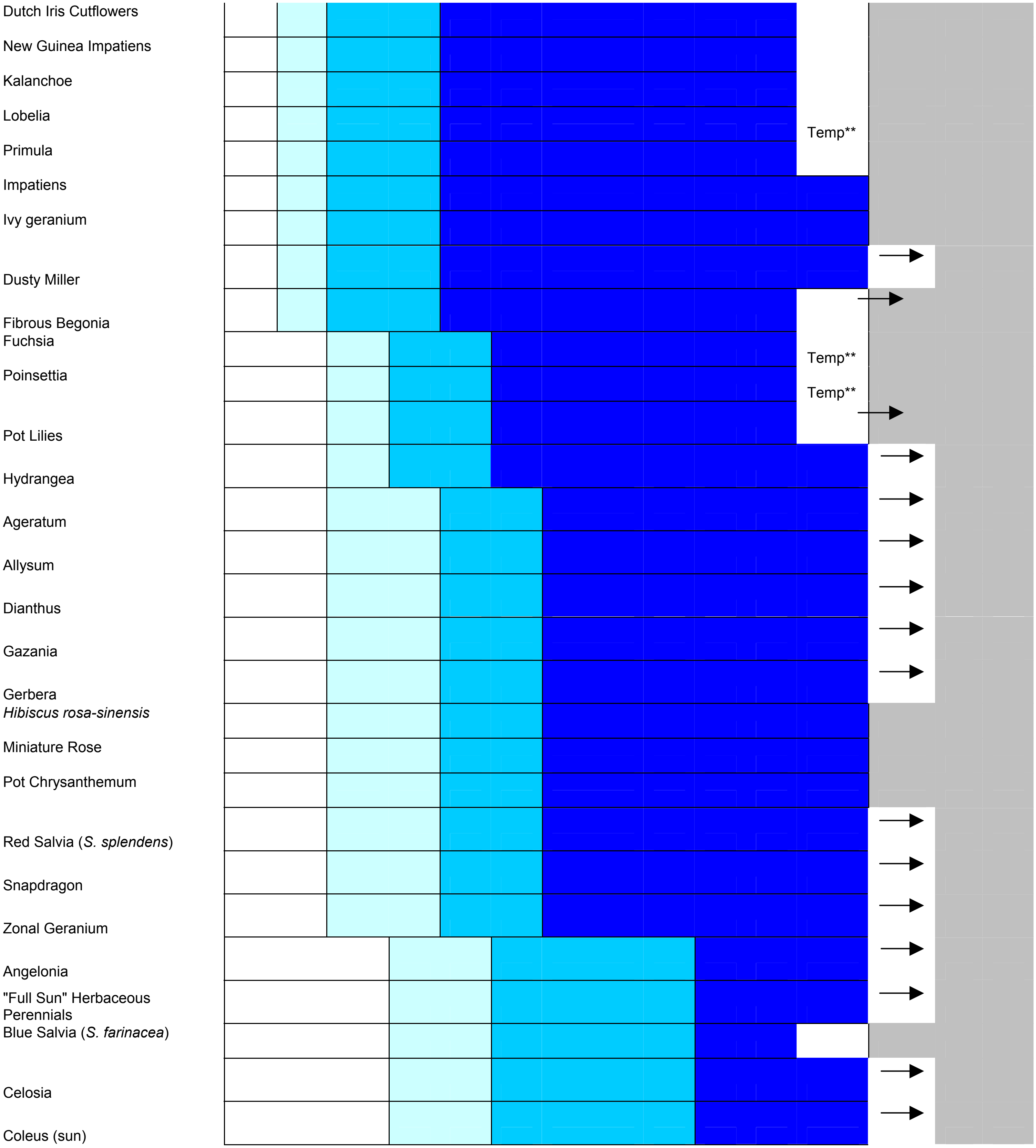
▒ Good quality

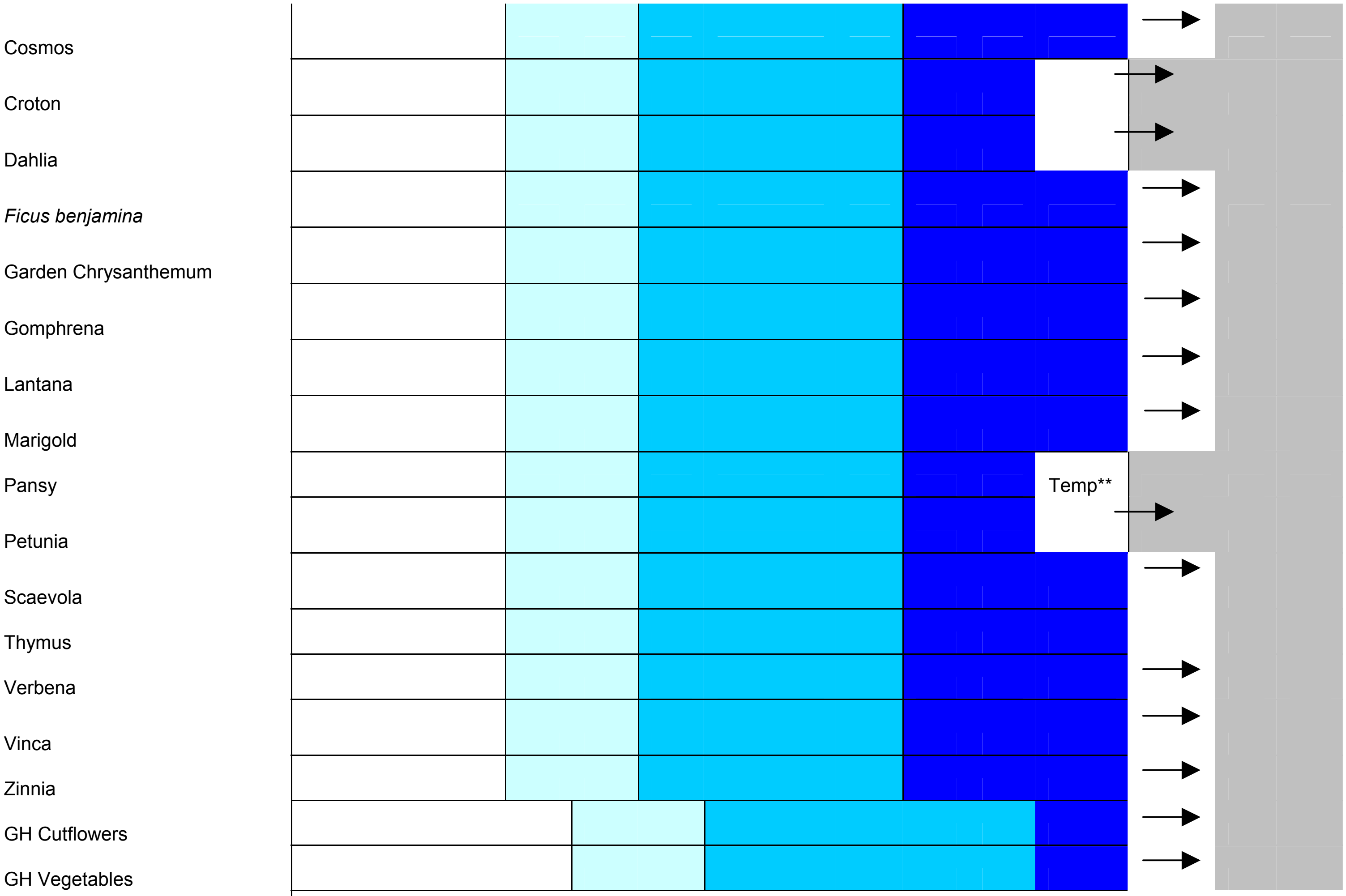
█ High quality

Daily Light Integral

(moles/day)

	GREENHOUSE											**OUTDOOR**		
Species	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**25**	**30**	**40**	**50**
African violet	░	▒	█	█	█									
Ferns (*Pteris, Adiantum*)	░	▒	█	█	█									
Maranta	░	▒	█	█	█									
Phalaenopsis Orchid	░	▒	█	█	█									
Spathiphyllum	░	▒	█	█	█									
Forced Dutch Bulbs	░	▒	█	█	█	█	█	█	█	█	█			
Foliage		░	▒	█	█	█	█							
Boston Fern		░	▒	█	█	█	█							
Bromeliads		░	▒	█	█	█	█							
Caladium		░	▒	█	█	█	█	█	█	█	Water*			
Streptocarpus		░	▒	█	█	█	█							
Hosta		░	▒	█	█	█	█	█	█	█	Water*			
Hedera (English ivy)		░	▒	▒	█	█	█	█	█	█	█			
Gloxinia		░	▒	▒	█	█	█	█						
Christmas Cactus		░	▒	▒	█	█	█	█	Temp**					
Hiemalis Begonia		░	▒	▒	█	█	█	█						
Exacum		░	▒	▒	█	█	█	█	█					
Cyclamen		░	▒	▒	█	█	█	█	█					
Heuchera		░	▒	▒	█	█	█	█	█					
Coleus (shade)		░	▒	▒	█	█	█	█	█	█				


Dutch Iris Cutflowers
New Guinea Impatiens
Kalanchoe
Lobelia
Temp**
Primula
Impatiens
Ivy geranium
Dusty Miller
Fibrous Begonia
Fuchsia
Temp**
Poinsettia
Temp**
Pot Lilies
Hydrangea
Ageratum
Allysum
Dianthus
Gazania
Gerbera
Hibiscus rosa-sinensis
Miniature Rose
Pot Chrysanthemum
Red Salvia (*S. splendens*)
Snapdragon
Zonal Geranium
Angelonia
"Full Sun" Herbaceous Perennials
Blue Salvia (*S. farinacea*)
Celosia
Coleus (sun)



*Water-Requires ample water to perform well at high light levels

**Temperature-Requires cool or moderate temperatures to perform well at high light levels

Arrows indicate that the species continues to perform well in full-sun outdoor conditions