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Net Photosynthesis of Three Foliage Plants under Low Irradiation Levels[1]

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Abstract. **Net CO_2 exchange, dark respiration, light compensation points, and light acclimatization rates were determined for *Brassaia actinophylla* Endl., *Nephrolepis exaltata* (L.) Schott 'Bostoniensis', and *Epipremnum aureum* (Linden & Andre) Bunt under 4 irradiation levels. These 3 species exhibited increased rates of net CO_2 uptake and decreased rates of dark respiration at the lowest irradiances, indicating an increase in photosynthetic efficiency. They demonstrated a 1.4 to 5.0 fold reduction in light compensation points over a 7 week period of acclimatization. *Brassaia actinophylla* reached its minimum light compensation point in 5 weeks, *Epipremnum aureum* in 3 weeks, and *Nephrolepsis exaltata* 'Bostoniensis' never reached a fixed light compensation point.**

Increased use of foliage plants for interiors has intensified concern for proper acclimatization to enhance their survival in new environments. Acclimatization refers to the climatic adaptation of an organism (plant) to a new environment (5); specifically, moving a foliage plant from the optimum conditions of greenhouse production to the limiting conditions of an interior environment. Research (3, 4) has shown that acclimatization prior to placement indoors is beneficial to most foliage plants. The length of acclimatization as well as the type of acclimatization varies for specific foliage plants.

Photosynthetically active radiation (PAR) in the 400-700 nm region is the most important factor in foliage plant acclimatization. Interior environments have low light intensities which places limitations on plants, both physiologically and metabolically (7). In order to survive these limitations, plants must adapt to these low PAR levels (1).

Previous work at Colorado State University, DePauw & DePauw (Unpublished data 1975), has shown that there is marked variation among plants within a species which can be attributed to the previous history of the plants. Secondly, plants grown under high levels of PAR have higher light compensation points than plants grown under low PAR levels. And thirdly, if plants are moved from high PAR to low PAR, a period of time is required for acclimatization before a new and lower light compensation point is reached, the light compensation point being the PAR level at which there is no net exchange of CO_2, or the point at which photosynthesis and respiration are essentially equal (13).

This study was undertaken to determine the rate and extent to which foliage plants grown in a greenhouse environment adapt to low PAR levels of interior environments.

Materials and Methods

Commercially salable plants in 15.2 cm pots were received March, 1977. Vegetatively produced *Nephrolepis exaltata* 'Bostoniensis' (Boston fern) and *Epipremnum aureum* and seed propagated *Brassaia actinophylla* (umbrella tree) were selected for their economic importance and taxonomic diversity. The potting media consisted of 1 part Canadian peat and 1 part #8 perlite. Each plant received a top dressing of 14g of a slow release fertilizer (14N–6.0P–11.6K) upon arrival. All plants were grown in a fiberglass-covered, air cooled greenhouse until the start of the light acclimatization experiments on July 7, 1977. The mean of maximum irradiation during this pretreatment period was 931 $\mu E \cdot m^{-2} \cdot sec^{-1}$.

Twelve plants of each species were selected for uniformity at experiment initiation. All remnants of slow-release fertilizer applied in March were removed, pots leached thoroughly and no additional fertilizer supplied to plants through the duration of the experiment.

A system to measure the rate of net CO_2 exchange for whole plants was designed to determine light compensation points and acclimatization rates. The system consisted of 2 distinct parts: 1) light acclimatization chambers which contained the foliage plants and their replicates, and sample chambers (Fig. 1 and 2) the infrared gas analysis system.

Walk-in light acclimatization chambers were built to create an isolated, fixed irradiation level, and to accommodate 9 whole plants (3 replications of 3 species) and the sample chamber. The irradiation source consisted of 4 double-tubed 40 Watt, Cool White, fluorescent fixtures and one 250 Watt, high pressure sodium lamp. Different irradiation levels in the chambers were accomplished by raising and lowering the fixtures and covering them with cheese cloth screens. Irradiation levels of 14, 29, 38, and 70 $\mu E \cdot m^{-2} \cdot sec^{-1}$ PAR were maintained for 14 hr daily. Chamber temperatures were maintained at 25°C ± 2.

The closed system sample chambers were constructed to obtain net CO_2 exchange rates for whole plants. Two small fans were mounted on different planes on adjacent sides of the

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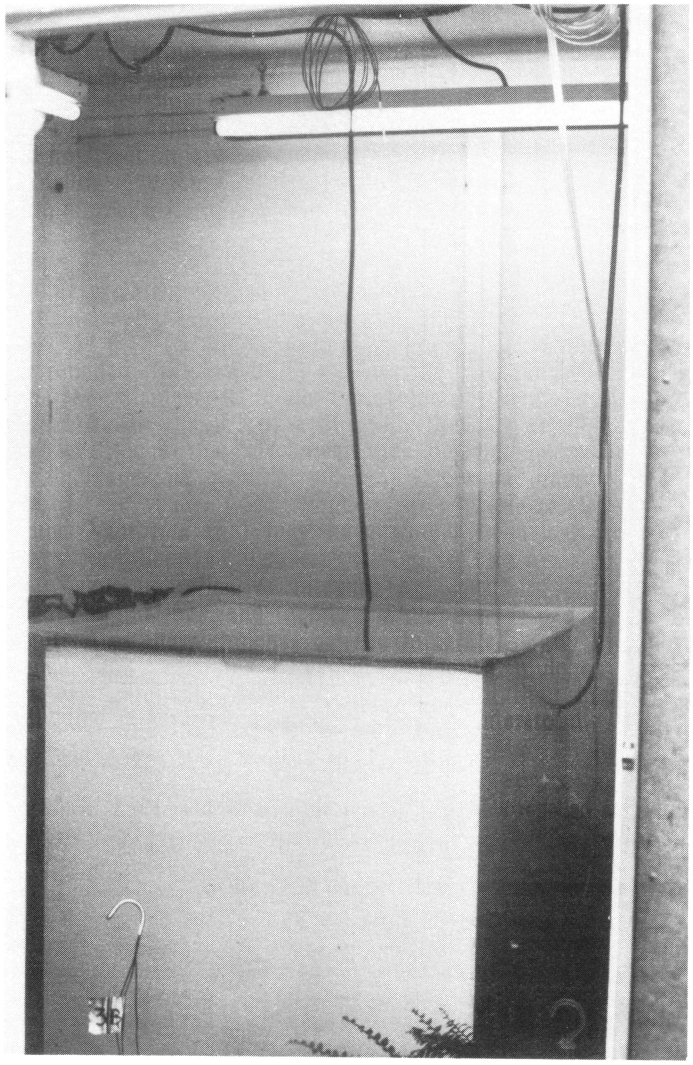

Fig. 1. A closed system sample chamber within a light acclimatization chamber for the measurement of net CO_2 exchange rates for whole plants under low irradiation levels.

sample chamber to create a homogenous CO_2 concentration. Ambient air temperatures within the light acclimatization chambers were responsible for temperature control of the sample chambers.

A differential infrared gas analyzer (IRGA) was used for all measurements of CO_2 exchange. Calibration checks were made at regular intervals using standard CO_2 in nitrogen. A flow rate of 420 ml/min was maintained from the sample chamber to the IRGA. The air sample from the sample chamber passed through a condensation trap, dew point sensor and dryer before analysis by the IRGA and returned to the same chamber. Chambers were connected to a solenoid valve system allowing sample gas from the appropriate sample chamber to be removed and returned on a timed basis.

Rates of net CO_2 exchange were measured by placing the replicated species in the closed system sample chamber in each of the light acclimatization chambers. The rate of CO_2 exchange was determined from the CO_2 increase or decrease in concentration for each chamber. Net CO_2 measurements were made on each plant 3 times a week for the 7 week duration of the experiment. The 3 weekly CO_2 measurements were averaged to give a mean net CO_2 exchange rate for weeks 1, 3, 5, and 7.

An attempt was made to measure root and soil respiration. Three replications of each species with all the photosynthetic area removed, were utilized for these measurements. The mean rate of respiration for the 3 species was about 0.03 mg $CO_2 \cdot pot^{-1} \cdot hr^{-1}$. An HSD mean separation test for these means showed no significant differences (P=5%).

Total leaf area was determined for each plant utilizing a portable leaf area meter. This permitted non-destructive, intact leaf area measurements.

All photosynthetic and respiratory rates determined for the experiment were computed by the equation (2):

$$P_n \text{ or } R_d = ((MVT_1P/LTP_1)\ (ppm/hr \times 10^{-6}))/LA$$

where: P_n = net photosynthesis (mg $CO_2 \cdot dm^{-2} \cdot hr^{-1}$)
R_d = dark respiration (mg $CO_2 \cdot dm^{-2} \cdot hr^{-1}$)
M = mole weight of CO_2 (44,010 mg)
V = volume of closed system (804.2 l)
T_1 = 273°K
P = average barometric pressure (635 mg Hg)
L = mole volume of CO_2 (22.414 l)
T = 298°K
P_1 = standard barometric pressure (760 mg Hg)
ppm/hr = CO_2 exchange rate in parts per million per hr converted to the volume fraction of CO_2 by multiplying by 10^{-6}
LA = leaf area of one side (dm^2)

Computed net CO_2 exchange rates at the 4 irradiation levels were subjected to linear regression analysis by species and an equation for each resulting line was obtained using the formula (7):

$y = B_1x + B_o$, where:

y = net CO_2 exchange rate
x = irradiance
B_1 = slope
B_o = y-intercept

Light compensation points were computed by substituting y = 0 into the equation and solving for x, the resulting formula for the light compensation points being $x = -B_o/B_1$ (7).

The experiment was treated as a split plot in design with species being main plots and acclimatization time as subplots. Analysis of variance was then performed on the net CO_2 exchange rates. When significant F-values were found, a Tukey's HSD mean separation test was used to determine significant differences (P=5%) among means.

Results

All 3 species exhibited net CO_2 exchange rates that decreased with decreasing levels of PAR (Table 1). At 70 $\mu E \cdot m^{-2} \cdot sec^{-1}$ of PAR there was always net CO_2 uptake over the 7 week period. However, the net amount of CO_2 fixed consistently decreased over the 7 weeks. At the lowest PAR level, 14 $\mu E \cdot m^{-2} \cdot sec^{-1}$, the CO_2 evolution diminished over the duration of the experiment. The CO_2 fixation, CO_2 evolution, and dark respiration rates were always greater during the first week of acclimatization (Tables 1 & 2).

Net CO_2 uptake for *Brassaia actinophylla* occurred at all PAR levels except for week one at 14 $\mu E \cdot m^{-2} \cdot sec^{-1}$ (Table 1). Although CO_2 uptake decreased over the course of the experiment, the rates were greater during the first week than during the following weeks. Dark respiration and consequential CO_2 evolution also diminished at all PAR levels during the experiment (Table 2). Dark CO_2 evolution decreased during weeks 1, 3 and 5 but no reduction occurred during the seventh week.

Net CO_2 uptake for *Nephrolepis exaltata* 'Bostoniensis' occurred at 70 $\mu E \cdot m^{-2} \cdot sec^{-1}$ PAR. CO_2 evolution took place at the lower PAR levels and was greater for weeks 1 and 3. CO_2 evolution decreased to week 5 and then leveled off. A large reduction in dark respiration occurred between weeks 1 and 3 but did not change for the rest of the experiment (Table 2).

Table 1. Mean net CO_2 uptake or evolution at four PAR levels for plants acclimatized after 1, 3, 5 and 7 weeks.

Species	Weeks	CO_2 uptake (+) or evolution (–) (mg $CO_2 \cdot dm^{-2} hr^{-1}$) PAR levels ($\mu E \cdot m^{-2} \cdot sec^{-1}$) 14	29	38	70
Brassaia actinophylla	1	–0.85a[z]	+1.11a	+1.80a	+8.11a
	3	+0.15b	+0.45b	+0.95b	+2.70b
	5	+0.20b	+0.48b	+0.82b	+1.96b
	7	+0.15b	+0.38b	+0.65b	+1.40b
Nephrolepis exaltata 'Bostoniensis'	1	–3.00a	–2.28a	–1.70a	+0.82a
	3	–2.01a	–1.21a	–1.03a	+0.67a
	5	–0.64b	–0.57b	–0.32b	+0.10b
	7	–0.13b	–0.07b	+0.03b	+0.10b
Epipremnum aureum	1	–1.27a	+0.62a	+1.56a	+4.81a
	3	–0.17b	+0.58b	+1.24b	+3.26b
	5	–0.15b	+0.44b	–0.98b	+1.02b
	7	–0.04b	+0.13b	+0.19b	+0.79b

[z]Mean separation for species in columns by Tukey's HSD test, 5% level.

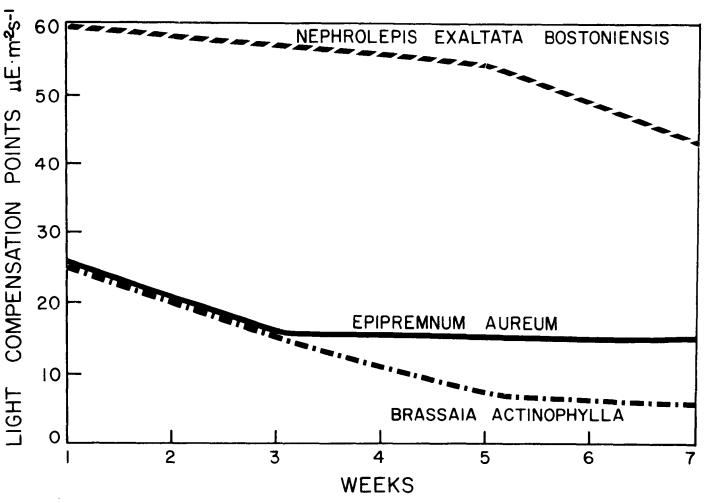

Fig. 2. Rates of acclimatization for *Brassaia actinophylla, Nephrolepis exaltata* 'Bostoniensis', and *Epipremnum aureum.*

CO_2 fixation for *Epipremnum aureum* took place at a diminishing rate for PAR levels 29, 38, and 70 $\mu E \cdot m^{-2} \cdot sec^{-1}$ (Table 1). CO_2 evolution resulted at the lowest irradiation level, 14 $\mu E \cdot m^{-2} \cdot sec^{-1}$. Less CO_2 was evolved during weeks 3, 5 and 7 than during week one. Dark respiration rates were lower for this species during week one, but, like the other species, also decreased during weeks 3 and 5 at all PAR levels (Table 2).

Brassaia actinophylla exhibited the most dramatic reduction in light compensation points of the 3 species tested (Fig. 2) where a 5-fold reduction in the light compensation point between week 1 and 7 occurred. *Nephrolepis exaltata* 'Bostoniensis' exhibited the highest light compensation points with a 1.4 fold reduction from week 1 to week 7 and the slowest rate of acclimatization. *Epipremnum aureum* was intermediate in acclimatization rate with a 1.7 fold reduction in light compensation points from week 1 to 7.

Discussion

Results of net CO_2 exchange and dark respiration demonstrated that *Brassaia actinophylla* was capable of the greatest photosynthetic efficiency at low PAR; *Epipremnum aureum* was intermediate, and *Nephrolepis exaltata* 'Bostoniensis' had the lowest photosynthetic efficiency. The changes that occurred during the process of acclimatization appeared to be caused by the plants' ability to photosynthesize more efficiently, with a reduction in respiration rates.

Increased photosynthetic efficiency may in part have resulted from changes in leaf morphology (6, 13). Older leaves of some species produced under high PAR may have improved photosynthetic efficiency at low PAR by increased chlorophyll production or reorientation of chloroplasts. New leaves produced under low PAR levels may have been larger, providing more surface area for maximum energy interception or chloroplasts might have oriented for maximum energy capture.

CO_2 evolution in the dark for the 3 species was significantly reduced during the 7 weeks of acclimatization. Reports in the literature indicate that plants grown in shade have lower respiration rates than those grown in exposed habitats (7, 8, 9, 10, 11, 12). McCree (10, 11) suggested that dark respiration could be characterized as having both maintenance and growth components. During acclimatization, the evident reduction in dark respiration may result from the change in relative importance of its 2 components, where the lower maintenance component was responsible for greater efficiency at the lower irradiation levels.

In an effort to explain the differences in light compensation points, McCree (11) gave evidence that the maintenance component of respiration dominated at the lower irradiation levels, and decreased with lowering of the irradiation to a minimum level. The light compensation point is a function of the photosynthesis-to-respiration ratio. By lowering the acclimatization irradiance, the maintenance respiration component is lowered allowing for efficient photosynthetic fixation of CO_2 at that new low PAR level. However, plants will reach a minimum PAR level which is dependent on plant species and production history.

Table 2. Mean dark respiration rates which represents CO_2 evolution in mg $CO_2 \cdot dm^{-2} \cdot hr^{-1}$ at four PAR levels for plants acclimatized after 1, 3, 5 and 7 weeks.

Species	Weeks	CO_2 evolution (mg $CO_2 \cdot dm^{-2} \cdot hr^{-1}$) PAR levels ($\mu E \cdot m^{-2} \cdot sec^{-1}$) 14	29	38	70
Brassaia actinophylla	1	–5.61a[z]	–6.24a	–6.46a	–6.00a
	3	–1.97b	–2.77b	–2.93b	–3.83b
	5	–1.25c	–1.16c	–1.31c	–1.74c
	7	–1.20c	–0.98c	–1.17c	–0.86c
Nephrolepis exaltata 'Bostoniensis'	1	–5.47a	–5.30a	–5.60a	–5.74a
	3	–1.95b	–2.20b	–2.22b	–2.11b
	5	–1.30b	–1.47b	–1.38b	–1.79b
	7	–1.18b	–1.19b	–1.03b	–1.13b
Epipremnum aureum	1	–3.19a	–3.21z	–4.00a	–4.42a
	3	–2.90b	–2.39b	–2.41b	–3.52b
	5	–1.12c	–1.15c	–1.74c	–2.59c
	7	–1.09c	–1.04c	–1.13c	–1.44c

[z]Mean separation for species in columns by Tukey's HSD test, 5% level.

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Relationships among Soil and Foliar Nutrient Levels and Plant Quality Variables in Field-grown Salvia Determined by Principal Component Analysis[1]

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Additional index words. statistics, nutrition, *Salvia splendens*

Abstract. **Principal component analysis of soil and foliar analysis and plant quality data for field-grown *Salvia splendens* Sello cv. Red Pillar was useful for pointing out relationships among these variables and suggested possible growth limiting factors. Soil P and foliar P, Ca, Cu, Zn, and N were found to be positively related to plant quality on the first principal component, whereas soil K, Ca, Mg, and NO_3 and foliar Fe were negatively related to quality. The former elements are thought to be limiting growth in this situation, while the latter elements in some way suppress the uptake or utilization of the deficient elements. The third and fourth components described well known relationships of soil pH with soil and foliar concentrations of several elements.**

Several studies have described correlations between pairs of soil or foliar nutrient variables (14, 15) or between foliar nutrient levels and crop yields (5, 6, 13, 16, 17). All these studies assume that the pair of variables being compared is independent of all others, however, the various individual components of the soil environment interact with each other and collectively affect plant composition and quality. For this reason, it would be more realistic to study nutrient interactions in the soil and foliage and their relationships to plant quality in a single integrated system.

A multivariate statistical technique which can be used to describe patterns of correlation within such a plant-soil ecosystem is principal component analysis (8). This method has been successfully used in agricultural research by Sinha et al. (11). Applications of this technique in horticulture science have been suggested (3, 10).

Patterns of correlation among soil and foliar nutrient levels and plant quality should indicate how these various nutrients are interacting in a given system and how they affect plant growth and quality. Such an analysis may suggest which elements are limiting plant growth and which are interacting to reduce the availability of the deficient elements to the plants. It was the purpose of this study to show how soil and foliar nutrient levels and plant quality variables are related in field-grown *Salvia splendens.*

Materials and Methods

Uniform 'Red Pillar' salvia transplants were grown outdoors in a Brookston silty clay loam soil during the summers of 1977 and 1978. Medium grade MagAmP 7.0N–17.5P–5.0K fertilizer was applied to the soil in 30 cm wide bands and incorporated at rates of 0, 14, 27, and 55 g actual N/m^2 to provide different soil fertility levels. Similarly, Osmocote 19.0N–2.6P–9.8K was applied at rates of 0, 36, 73, and 146 g actual N/m^2. Specific treatments used in this study have no significance in the analysis and were applied solely to provide varying soil fertility levels over a 4 month period. A randomized complete block with 3 replicates each year was utilized for convenience, however, for purposes of this analysis, each treatment for each sampling date was treated as a separate replicate so that a total of 56 complete replicates over a 2 year period were used. Salvia were planted 30 cm apart in rows spaced 90 cm apart on May 17, 1977 and May 22, 1978. Plants were irrigated as necessary, applying about 2.5 cm of water each time with an overhead irrigation system and were maintained virtually weedfree by manual and mechanical cultivation.

Four weeks after planting, measurements of plant height, average width, shoot dry weight, and number of inflorescences were recorded for 1 row of 10 plants in each plot. Soil samples taken at this time were analyzed for pH, soluble salts, and available P, Ca, Mg, K, and NO_3 levels. Foliar samples consisting of only recently matured leaves and petioles were also taken and

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