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Growth and Light Utilization of Pot Plants at Variable Day-to-day Irradiances

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Summary

The aim of this study was to examine the effect of 50, 100, 150 and 200 (μmol m^{-2} s^{-1} photon flux densities (PFD), supplied daily, every second, third or fourth day, on growth and flowering of pot roses, *Kalanchoe blossfeldiana* and *Begonia* x *hiemalis*. The 16 different light treatments gave photosynthetic active radiation (PAR) ranging from a mean of 0.9 to 14.4 mol m^{-2} day^{-1}. Increasing the PFD from the lowest to the highest level or increasing the lighting frequency from every fourth day to every day gradually reduced the time until flowering in all three species. Plant dry weight and mean growth rate per day were increased when the PFD was increased from 50 to 150 μmol m^{-2} s^{-1}, while a further increase to 200 μmol m^{-2} s^{-1} had no effect irrespective of lighting frequency. The mean light utilization, defined as dry weight produced per plant per mol m^{-2} day^{-1}, was increased by decreasing the PFD or lighting frequency. It was concluded that low daily PAR during 1–3 days could not be compensated for by high PAR during the other days. In order to obtain good plant growth, a sufficient level of PAR must be applied daily.

Zusammenfassung

Wachstum und Lichtverwertung von Topfpflanzen bei variabler Tag-für-Tag Belichtung. Ziel dieser Untersuchung war, die Wirkung einer Photonenflussdichte (PFD) von 50, 100, 150 und 200 (μmol m^{-2} s^{-1}, die täglich bzw. jeden zweiten, dritten oder vierten Tag verabreicht wurde, auf das Wachstum und die Blüte von Topfrosen, *Kalanchoe blossfeldiana* und *Begonia* x *hiemalis* zu prüfen. Die 16 unterschiedlichen Lichtbehandlungen erbrachten im Mittel 0.9 bis 14.4 mol m^{-2} day^{-1} photosynthetisch aktive Bestrahlung (PAR). Die Erhöhung der PFD vom geringsten zum höchsten Wert oder der Belichtungshäufigkeit von jeden vierten Tage auf täglich, reduzierten die Dauer bis zur Blüte bei allen drei Arten. Das Trockengewicht und die durchschnittliche Wachstumsrate stiegen an, wenn die PFD von 50 auf 150 μmol m^{-2} s^{-1} erhöht wurde; allerdings blieb eine weiter Erhöhung auf 200 μmol m^{-2} s^{-1}, unabhängig von der Belichtungshäufigkeit, ohne Wirkung. Die mittlere Lichtverwertung, definiert als gebildetes Trockengewicht pro Pflanze und mol m^{-2} day^{-1}, erhöhte sich mit abnehmender PFD oder Belichtungshäufigkeit. Daraus kann gefolgert werden, dass geringe tägliche PAR während 1–3 Tagen, nicht durch hohe PAR während der übrigen Tage kompensiert werden kann. Um gutes Pflanzenwachstum zu erzielen, muss täglich eine ausreichende PAR verabreicht werden.

Key words. Pot rose – *Begonia* – *Kalanchoe* – growth – variable irradiance

Introduction

At high latitudes in Scandinavia (55–70 °N) photosynthetic active radiation (PAR) varies considerably throughout the year (WALLEN 1970). Inside a greenhouse, typical values are 0–2 mol m^{-2} day^{-1} PAR in December–January and 20–25 mol m^{-2} day^{-1} in May–July (MORTENSEN et al. 2000). Owing to low PAR during winter, supplementary lighting is necessary to obtain efficient greenhouse production. Today, flowering pot plants can be produced in commercial greenhouses in Norway using 100–150 μmol m^{-2} s^{-1} PFD supplementary lighting (high pressure sodium lamps) for 20 h day^{-1}, corresponding to 7.2–10.8 mol m^{-2} day^{-1} PAR. The increasing cost of electricity in recent years has focused efforts on how to use supplementary light as efficiently as possible. During spring (March–April) and autumn (September–October), however, when daylight can vary from day to day from about 1 to 20 mol m^{-2} day^{-1}, the demand for supplementary light on a daily basis can also vary considerably. The average daylight per day in the course of a week can be sufficient to give good growth (7–10 mol m^{-2} day^{-1} PAR), but the question is whether a low PAR level for one day can be compensated by high PAR levels during the other days. If this were the case, the use of artificial light could be reduced and electrical energy saved. This study, including three important flowering pot plants, was designed to find an answer to this question. Judging from other published works, it seems that a study of this kind has never been carried out before.

Materials and Methods

Small plants of *Begonia* × *hiemalis* cv. 'Barkos', *Rosa* sp. cv. 'Golden Hit' (pot rose) and *Kalanchoe blossfeldiana* cv.

Table 1. The average daily PAR (mol m^{-2} day^{-1}) supplied in addition to daylight (0.9 mol m^{-2} day^{-1}) in the different light treatments.

	Lighting frequency			
PFD (μmol m–2 s–1)	Every day	Every second day	Every third day	Every fourth day
50	3.6	1.8	1.2	0.9
100	7.2	3.6	2.4	1.8
150	10.8	5.4	3.6	2.7
200	14.4	7.2	4.8	3.6

Table 2. Significance levels of main effects and interactions between photon flux density (PFD) and lighting frequency (Freq.) on different growth parameters in three pot plant species.

	Pot roses			*Kalanchoe*			*Begonia*		
	PFD	Freq.	PFD x Freq.	PFD	Freq.	PFD x Freq.	PFD	Freq.	PFD x Freq.
Time until flowering	***	***	ns	***	***	**	***	***	ns
No. of flowers	***	***	**	***	***	*	ns	ns	ns
Plant dry weight	***	***	**	***	***	**	***	***	*
Growth rate	***	***	***	***	***	***	***	***	***
Light use efficiency	***	***	ns	***	***	ns	***	***	*

Significance levels: ns: not significant; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

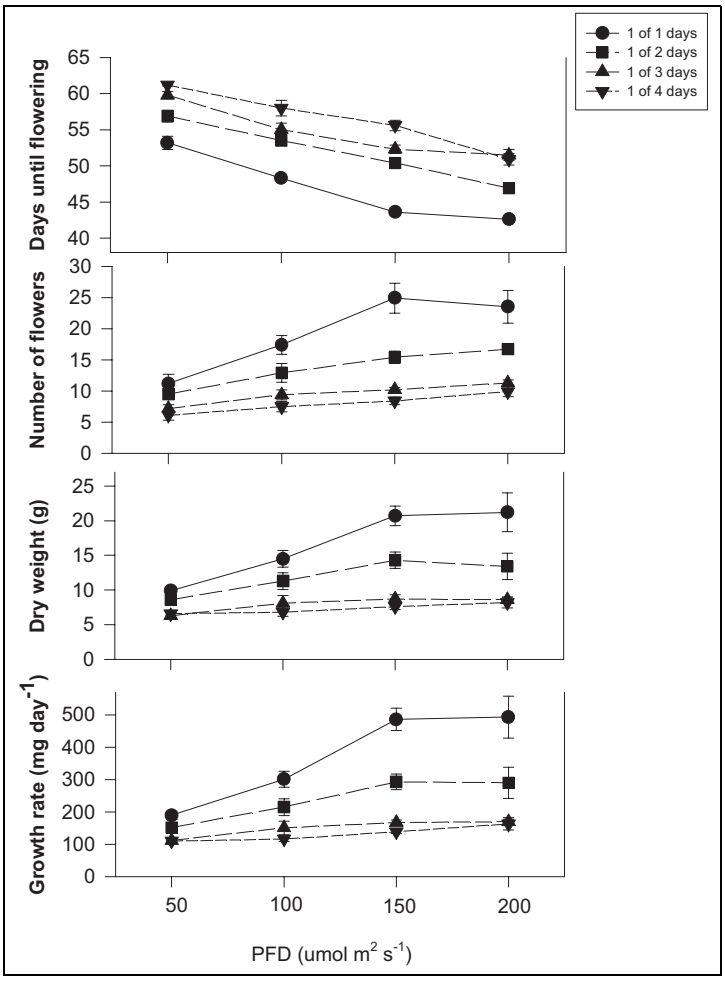


Fig. 1. The effect of four levels of supplementary lighting (PFD) given daily (1 of 1 day), every second (1 of 2 days), every third (1 of 3 days) and every fourth day (1 of 4 days) on the growth of pot roses.

'Debbie' planted in standard fertilized peat (Floralux, Nittedal industrier) in 11-cm (*Kalanchoe*) or 12-cm pots (pot rose and *Begonia*) were used in the experiment. In pot rose, five cuttings were used per pot, and the experiment started after the second pinching, 2 cm above the pot edge. The *Kalanchoe* and *Begonia* plants had been given 5 weeks of short-day treatment (10 h day^{-1}) before the start of the experiment. The plant dry weight of *Kalanchoe* was 1.9 g and of *Begonia* 1.1 g at the start of the experiment. The plants were grown in a greenhouse compartment at four photon flux densities (50, 100, 150 and 200 μmol m^{-2} s^{-1} PFD) given daily, every second, third or fourth day. The average daily PAR produced by the different light treatments are presented in Table 1.

The light was supplied by high-pressure sodium lamps (Philips SON/T) for 20 h day^{-1} and was measured using a Lambda LI-185B instrument with a quantum sensor above the plants. The four PFD levels were established above each of four greenhouse tables, one at each of the four different lighting frequencies (daily, every second day, etc.). The different lighting frequencies were separated by white plastic film. All treatments were subjected to a photoperiod of 20 h day^{-1} by applying 1 μmol m^{-2} s^{-1} PFD during the days when the lamps were switched off.

The temperature was measured by thermocouples and was recorded as hourly means. The air temperature was measured at the lowest (50 μmol m^{-2} s^{-1}) and highest PFD levels (200 μmol m^{-2} s^{-1}) at the four different lighting frequencies in all three species. In addition, the temperature was measured at all PFD levels in the treatment with daily lighting. Altogether, the air temperature was measured at 30 different locations at the top of the plants. The mean temperature throughout the experiment in all three species was 19.2, 19.4, 20.1 and 20.5 °C at 50, 100, 150 and 200 μmol m^{-2} s^{-1}, respectively, with daily lighting. The mean air temperature increased from 18.7 to 19.4 °C when the PFD was increased from 50 to 200 μmol m^{-2} s^{-1} by lighting every second, third and fourth day.

Relative air humidity was 70–75 % as measured by Vaisala air humidity sensors (HMP 35A), and the CO_2 concentration was 650±50 μmol mol^{-1} as measured by an infrared gas analyser. The contribution of daylight at the top of the plants was a mean of 0.9 mol m^{-2} day^{-1} PAR during the experimental period (measured at the Meteorological Station at Særheim Research Centre). Twelve plants, divided into three groups of four plants, were used in each of the 16 light treatments for all three species.

The plants were watered regularly with a complete nutrient solution, as previously described (MORTENSEN and FJELD 1998), and the soil salinity was maintained at about 2.0 mS cm^{-1} (electrical conductivity) and pH at

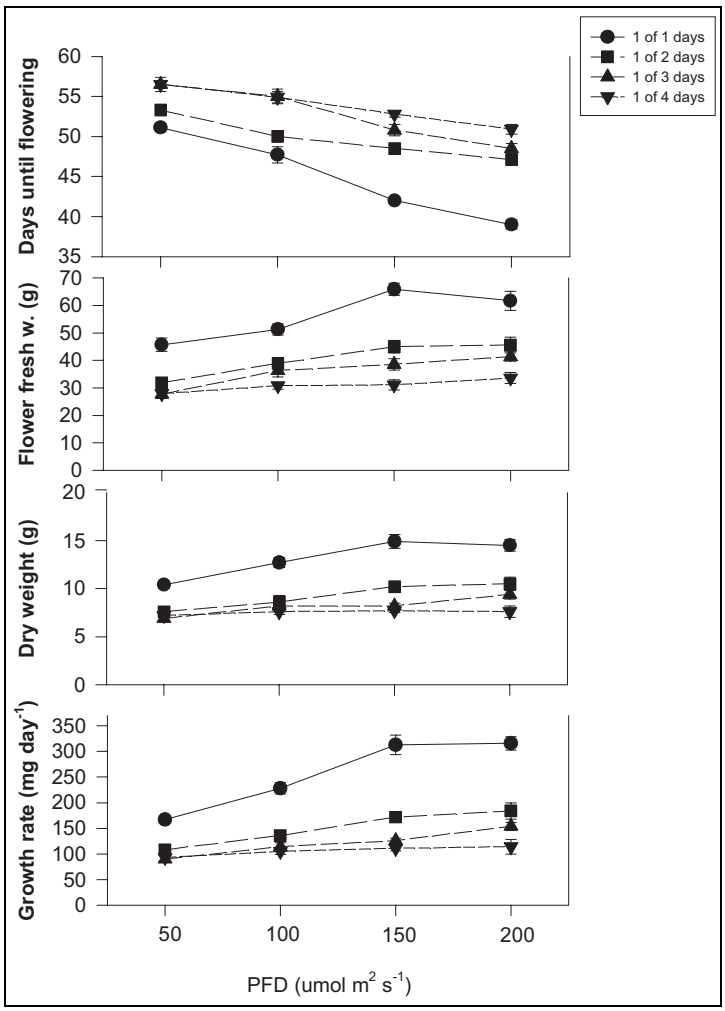


Fig. 2. The effect of four levels of supplementary lighting (PFD) given daily (1 of 1 day), every second (1 of 2 days), every third (1 of 3 days) and every fourth day (1 of 4 days) on the growth of *Kalanchoe*.

5.0–5.5. The experiment started on 23, 27 and 30 January with pot roses, *Begonia* and *Kalanchoe*, respectively.

At saleable stage (5–10 open flowers) the plants were harvested and plant height, number of open flowers plus flower buds (pot roses and *Begonia*), fresh weight of flowers and flower stems (*Kalanchoe*) and plant fresh and dry weights were recorded. The mean growth rate per day was calculated by dividing the dry weight increment (dry weight at saleable stage minus initial dry weight) by days until harvest. The light use efficiency was calculated by dividing the growth rate on number of mol m^{-2} day^{-1}.

All data were subjected to an analysis of variance using the SAS-GLM procedure (SAS Institute Inc., Cary, USA). Plant groups of four plants each were used as replicates.

Results

Pot roses

Increasing the PFD from 50 to 200 μmol m^{-2} s^{-1} gradually decreased the number of days until flowering in pot roses by about 10 days at all lighting frequencies (Table 2, Fig. 1). Time until flowering was shortest with a daily lighting frequency, and increased as the lighting frequency decreased to each fourth day (Fig. 1). The total number of open flowers and flower buds was enhanced by increasing PFD to 150 μmol m^{-2} s^{-1} with daily lighting, while PFD was increased slightly further, to 200 μmol m^{-2} s^{-1}, in the other lighting frequencies. The number decreased as the lighting frequency decreased from daily to every fourth day irrespective of PFD. Plant dry weight and mean growth rate per day increased as the PFD increased to 150 μmol m^{-2} s^{-1}, while a further increase to 200 μmol m^{-2} s^{-1} had only a minor effect at all lighting frequencies (Fig. 1). Decreasing the lighting frequency from daily to every fourth day proportionately decreased the dry weight and mean growth rate at all PFD levels. Growth rate at the two highest PFD levels was 70 % higher with daily lighting than with lighting every second day.

Kalanchoe

Increasing the PFD from the lowest to the highest PFD decreased time until flowering significantly at all lighting frequencies, but particularly when lighting was supplied daily (Table 2, Fig. 2). The flower and flower stem weight increased when PFD was increased up to 150 μmol m^{-2} s^{-1} at all lighting frequencies, while a further increase in PFD had only a small effect. Plant dry weight and mean growth rate per day increased as the PFD increased up to 150 μmol m^{-2} s^{-1}, particularly

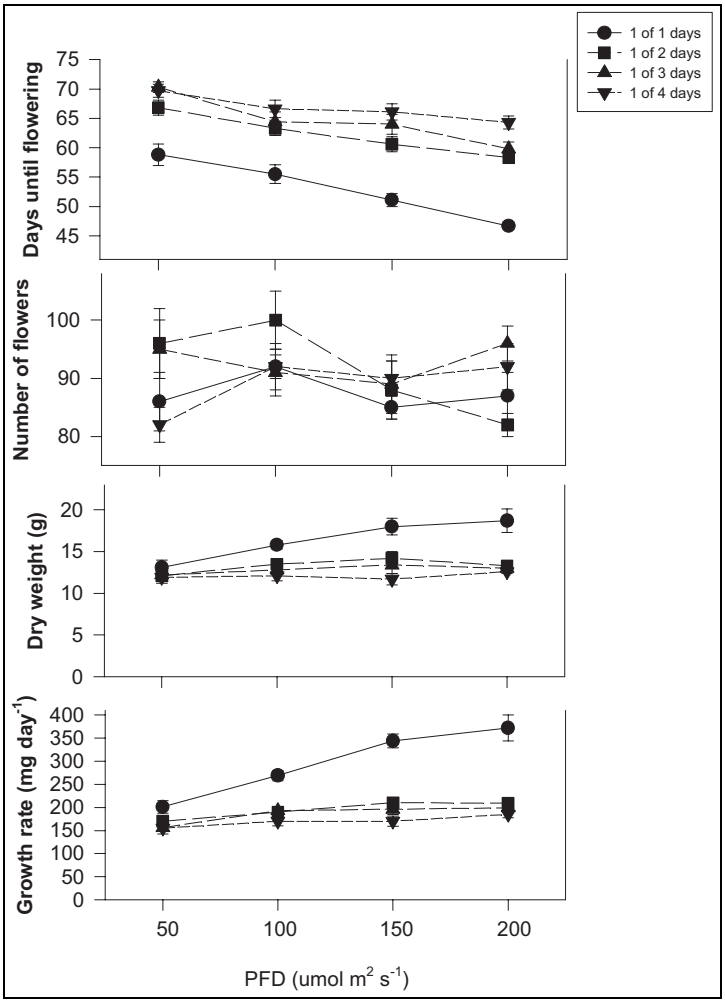


Fig. 3. The effect of four levels of supplementary lighting (PFD) given daily (1 of 1 day), every second (1 of 2 days), every third (1 of 3 days) and every fourth day (1 of 4 days) on the growth of *Begonia*.

when light was supplied daily, and less with decreasing lighting frequency. The growth rate at the two highest PFD levels was 75 % higher with daily lighting than with lighting every second day.

Begonia

Increasing the PFD from the lowest to the highest level gradually decreased time until flowering at all lighting frequencies, but more so with the daily lighting regime than with less frequent lighting (Table 2, Fig. 3). At time of flowering, the total number of open flowers plus flower buds (85–95) was not significantly affected by PFD or lighting frequency (data not presented). With daily lighting, plant dry weight and mean growth rate per day increased significantly as the PFD was increased from 50 to 150 μmol m^{-2} s^{-1}, while a further increase to 200 μmol m^{-2} s^{-1} gave only a slight increase. With lighting every second, third or fourth day, the effect of an increase in PFD on dry weight and growth rate was relatively small. The growth rate at the two highest PFD levels was about 70 % higher with daily lighting than with lighting every second day.

Light-use efficiency

Light-use efficiency, expressed as mean daily plant dry weight increase per mol m^{-2} day^{-1}, was calculated for the different light treatments (Table 2, Fig. 4). For all three species the efficiency decreased significantly with increasing PAR of the treatment. Light-use efficiency was reduced by 21 %, 43 % and 44 % in the pot roses, *Kalanchoe* and *Begonia*, when the PAR increased from the lowest (4.5 mol m^{-2} day^{-1}) to the highest level (15.3 mol m^{-2} day^{-1}) with daily lighting. Decreasing the PAR to below 4.5 mol m^{-2} day^{-1} (daily 50 μmol m^{-2} s^{-1} in 20 h day^{-1} plus 0.9 mol m^{-2} day^{-1} daylight) by less frequent lighting further increased light-use efficiency. In pot roses and *Kalanchoe*, the effect of increasing PFD was similar at all lighting frequencies, while light-use efficiency was less reduced with increasing PFD with daily lighting than when the lighting was given less frequently. When light-use efficiency was related to average daily PAR irrespective of light treatment, it appeared that the efficiency decreased slower at increasing PAR in pot roses as compared to in *Kalanchoe*, and particularly compared to in *Begonia* (Fig. 5).

Discussion

The most important conclusion that can be drawn from the present study was that the pot plants in general were unable to utilize PFD levels above 150 μmol m^{-2} s^{-1} (a daily PAR of 11 mol m^{-2}), which is in concordance with previous results with *Begonia*

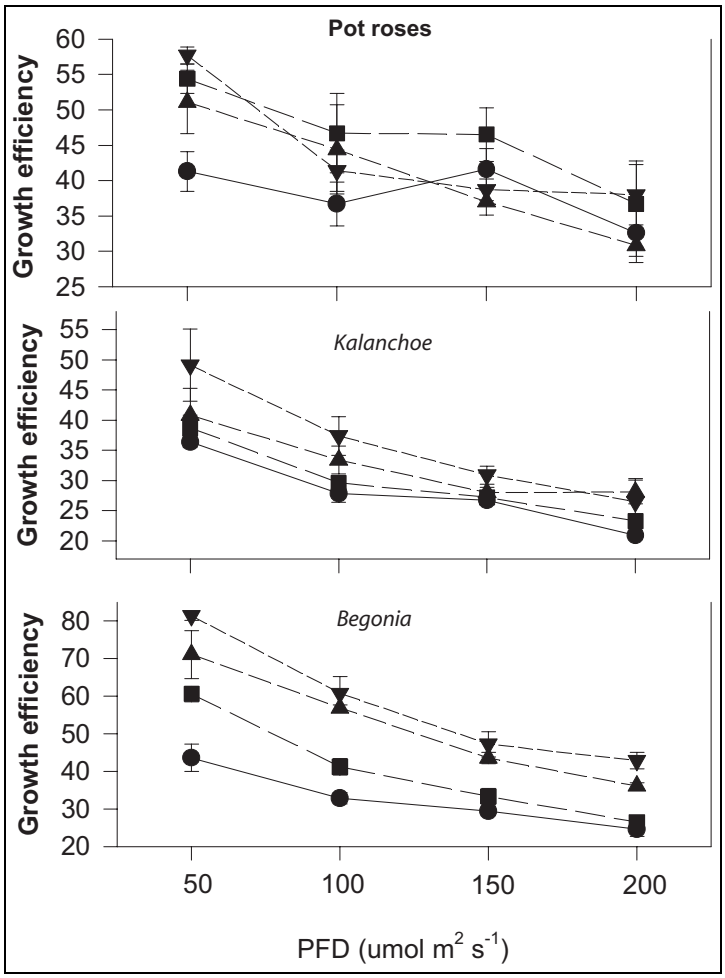


Fig. 4. The effect of four levels of supplementary lighting (PFD) given daily (1 of 1 day), every second (1 of 2 days), every third (1 of 3 days) and every fourth day (1 of 4 days) on light-use efficiency [mean dry weight (mg) increase per day and mol m^{-2} day^{-1}] in three different pot plant species.

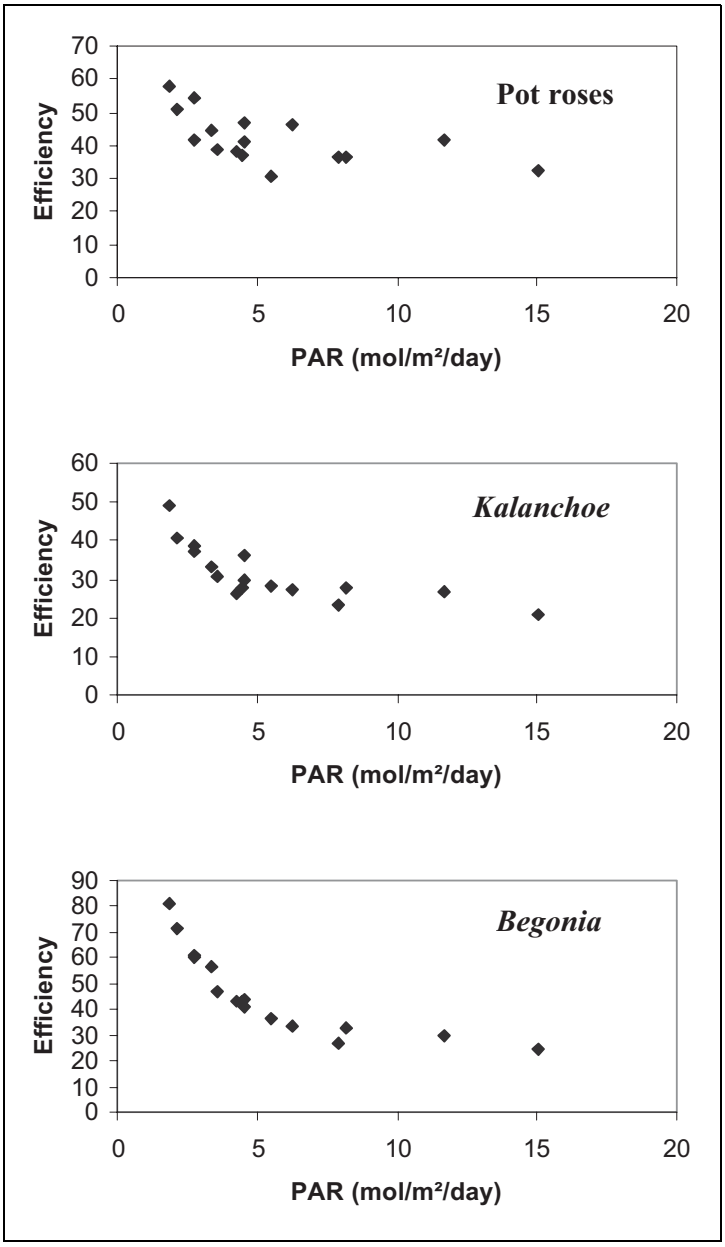


Fig. 5. The relationship between light-use efficiency (see Fig. 4 text) and photosynthetic active radiation (PAR) in the 16 different light treatments in pot roses (top), *Kalanchoe* (in the middle) and *Begonia* (bottom).

(MORTENSEN and ULSAKER 1985). A consequence is that the plants are unable to utilize much of the PAR from the daylight because a significant proportion of the light is intercepted as PFD levels above 150 μmol m^{-2} s^{-1} in the period April to September (MORTENSEN et al. 2000). The present results show that this conclusion is unlikely to change even if a sunny day follows one or more days of low PAR. If this inability of the pot plants to derive benefit from PFD levels higher than 150 μmol m^{-2} s^{-1} is taken into account, the effective PAR will not exceed 10 mol m^{-2} day^{-1} even on clear days in summer (MORTENSEN et al. 2000). This is less than one-third of the PAR inside a greenhouse on sunny days in summer (about 30 mol m^{-2} day^{-1}) in Europe. During the summer months, with more or less the same daily PAR between latitudes of 45 ° and 70 °N (WALLEN 1970), the effective PAR will decrease with decreasing latitude. This is because of longer days with lower maximum PFD levels with increasing latitudes. In order to maximize the growth rate of pot plants, increasing the lighting period from 12 h to 18–20 h day^{-1} will generally be more effective than increasing the PFD level (GISLERØD et al. 1989; MORTENSEN 1994; BAKKEN and BÆVRE 1999).

It is emphasized that the limit of 150 μmol m^{-2} s^{-1}, above which there are only small effects on growth rates, is related to pot plants with a relatively low biomass and low leaf area indexes. In contrast to the findings with pot roses, the growth and yield of cut roses have been shown to increase to supplementary PFD levels of about 400 μmol m^{-2} s^{-1} (MORTENSEN et al. 1992). Probably because of the voluminous growth and high leaf area indexes, photosynthesis of cut roses increases to PFD levels of about 1000 μmol m^{-2} s^{-1} (JIAO et al. 1988; MORTENSEN 1995).

When the PFD level increases, the air temperature surrounding the plants is likely to increase too, as measured in the present study. In practice, it is difficult to

prevent a temperature increase when the PFD is increased by artificial light or daylight. The effect of increased PFD levels can therefore be partly attributable to increased temperature, as in roses, where time until flowering is strongly influenced by temperature (MOE 1972; MORTENSEN 1994). However, this has no bearing on the conclusion of the present study, since a rise in temperature is more likely to increase the saturating PFD level than decrease it.

Greenhouse plants are known to acclimatize to decreased PFD by reducing the light compensation point. They thus have a positive growth rate even in low light conditions (MORTENSEN and OLSEN 1987). This process is linked mainly to reduced dark respiration rates (BOARDMAN 1977). The process of light acclimation to low light does not stimulate the ability of plants to derive any benefit from sporadic, high PAR levels. When the PAR is lowered by reducing the lighting period and/or the PFD, the light-use efficiency of plants is increased (BJØRKMAN and HOLMGREN 1963; ARMITAGE and VINES 1982), as also found in the present study. However, an increased ability to use low light levels is generally found to correlate with a reduced ability to utilize high light levels. This indicates that greenhouse plants grown in good light conditions should be more able to utilize occasional high PFD levels than if grown in generally low light conditions.

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