out of four seasons’ trials on a nursery site (5). A similar pattern
was observed with deciduous *Azalea* at Efford (6). In the first year,
rooting improved 42% with etiolated deciduous *Berriesore* *Azalea*
cuttings, but *Botrytis* under the etiolation cages caused abandonment
of the trial in the second year. Black polyethylene was used in this
work; further investigation on a development scale with black
permeable materials is needed.

**Shade structures**

Growing under permanent shade houses improves the quality of
stock plants and could be economical for more valuable or shade-
requiring species (e.g., *Camellia, Rhododendron, Skimmia, Eu-
chyphila, Magnolia*, and *Fleris*). Improvement of *Camellia* is par-
ticularly striking under shade.

**CONCLUSIONS**

Benefits of a separate stock area, rather than taking cutting ma-
terial from isolated specimens or salable plants, have been dem-
onstrated clearly since the beds were planted. Not only has greater
uniformity in the type of material available and ease of manage-
ment been achieved, but there also has been a striking improvement in
overall quality of plants in the subsequent experimental (research)
plots.

A considerable amount of information has been gleaned on stock
bed management from these observations; however, detailed work
is required on herbicide programs and pruning to achieve maximum
cutting potential of various species and timing of growth flushes as
influenced by forcing technique. Greater understanding of cutting
pretreatment techniques on stock plants (i.e., etiolation, growth
regulators) is required to see whether cutting production and/or root-
ing can be improved for selected species. Rooting potential of cut-
tings from micropropagated plants as compared with conventionally
propagated material also needs investigation, since there are indica-
tions that the former will root more easily.

The Efford stock collection is clonal in source to increase uni-
formity for experimental work. Its advantages make it a worthwhile
consideration for the commercial situation. This can be done either
by progeny selection of the best plant from an established area as
replanting becomes due, or by taking up the clones as they are
released to the trade from "Clonal Selection Schemes".

In conclusion, the final quality of the plant produced is dependent
on many factors, but it begins with the stock and type of cutting
taken. The need for well-graded quality cuttings is an essential
starting point in any production schedule. Attention to detail and
the setting of high standards in the stock-plant area will ensure this
good start in the production cycle, which will be reflected through-
out the life of the crop.

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**Effect of Carbon Dioxide Enrichment During Stock
Plant Cultivation**

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Carbon dioxide enrichment has become an important factor in
ornamental plant production during the past few years. Nurseries,
especially those producing cuttings or young plants, increasingly
use CO\(_2\) enrichment during stock plant cultivation and propagation.
This development was brought about by new and inexpensive equip-
ment for measuring and regulating greenhouse CO\(_2\) concentrations.
Although the positive effect of CO\(_2\) enrichment on plant growth has been
well established by previous investigations (3, 4, 6, 8, 9), optimum CO\(_2\)
concentrations have not been clearly defined. Only a few previous investigations have dealt with the influence of CO\(_2\)
enrichment on the growth and yield of stock plants and on successful
propagation (1, 2, 5, 7, 10). Therefore, the aim of this study was to
find optimum CO\(_2\) concentrations for stock plant cultivation and
for the propagation of different plant species. Results with only five
cultivars and species are presented, although 15 different species
were tested.

Cultivars of five different species [ *Pelargonium x zonale* (L.) L’
Héritier et Ait. ‘Empress’; *Pelargonium x peltatum* (L.) L’Hér. et Ait.
‘Lachsönnigin’; *Chrysanthemum x indicum* (L.) ‘Trumpf’; *Fuchsia x
hybrida* Hort. ex Vilm. ‘Hanna’; and *Saintpaulia ionantha* H. Wendl. ‘Typ 6’] were grown as stock plants in four greenhouse compartments with different CO\(_2\) concentrations: ambient (350-
450), 800, 1200, and 1600 µl liter\(^{-1}\). Carbon dioxide was applied
daily as soon as the light intensity exceeded 200 lx and CO\(_2\) ap-
lication ceased when the light intensity dropped below 200 lx. To
avoid effects of components other than CO\(_2\), CO\(_2\) was used only
in the liquid form. The CO\(_2\) concentration was measured by a Sie-
mens CO\(_2\) analyzer at short intervals and was regulated by Dansk
Gartneriteknik AS (DGT) equipment. Trials were carried out dur-
ing the winter (October–March), when the greenhouse vents were
mostly closed.

**Stock plant cultivation.** Stock plants were grown in a standard
fertilized peat-clay mixture (Einheitserde P) in plastic pots,
containers, or plastic trays. Plant density was 37 plants/m\(^2\) for the
Pelargonium cultivars, 66.7 plants/m\(^2\) for *Chrysanthemums*, 44.4
plants/m\(^2\) for the Fuchsias, and 300 tufts/m\(^2\) for the *Saintpaulias.

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There were four replications per treatment. Fertilizer was applied weekly by watering with a 15N-4.8P-12.5K complete nutrient solution (Flory 3) at a concentration of 0.2% or 0.4%. Nutrient content of the substrates was adjusted once a month. Variations due to differential nutrient uptake were equalized through supplemental fertilization. The temperature was held at 18°C; except for the Saint-paulias, which were grown at 20°C day and night. To ensure long-day conditions, the natural daylength was extended for the Chrysanthemums to 16 hr with 150-300 lx incandescent light.

Propagation. Cuttings were harvested once a week, counted, and fresh and dry weights recorded. Cuttings were used for propagation experiments every 2 or 3 weeks. Cuttings produced under each CO₂ treatment were inserted into a special propagation medium, and the flats from each CO₂ trial were distributed for rooting to the compartments with the different CO₂ enrichment levels. There were four replications per treatment. Increase of fresh weight was recorded at the end of the 2- or 3-week propagation period and was used as an index for propagation success.

Yield of the stock plants. Cutting yields are defined as the sum of the harvests during the stock plant cultivation period from November to March. Stock plants of Pelargonium × zonale ‘Empress’ grown at a CO₂ concentration of 1600 μl-liter⁻¹ produced 50% more cuttings than control plants (Fig. 1). Similar results were obtained with the Pelargonium × peltatum ‘Lachskönigin’ (Fig. 2). Carbon dioxide enrichment of 1200 (1600) μl-liter⁻¹ resulted in a 35% to 40% higher yield of cuttings.

In the most instances, CO₂ enrichment of 1200 μl-liter⁻¹ led to the best growth of the stock plants. At that concentration, Chrysanthemum × indicum ‘Trumpf’ yielded 27% more cuttings than the untreated controls (Fig. 3). Raising the CO₂ concentration to 1600

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**Fig. 1.** Cutting yields of Pelargonium × zonale ‘Empress’ following different CO₂ enrichment levels (μl 1⁻¹ = microliters per liter).

**Fig. 2.** Cutting yields of Pelargonium × peltatum ‘Lachskönigin’ following different CO₂ enrichment levels (μl 1⁻¹ = microliters per liter).
number of cuttings
/sq.m /stock plant

2000  20

number of cuttings
/sq.m /stock plant

2000  20

μl·liter⁻¹ led to no further increase in yield.

Similar results were obtained with the Fuchsia x hybrida ‘Hanna’ (Fig. 4). Carbon dioxide enrichment of 1200 μl·liter⁻¹ enhanced the cutting yield by about 50%, whereas the higher concentration of 1600 μl·liter⁻¹ had no further influence on yield. In contrast to these findings, in which CO₂ concentrations of 1200 μl·liter⁻¹ and higher led to the best results, the optimum CO₂ concentration for Saintpaulia ionantha was 800 μl·liter⁻¹ (Fig. 5). Of all plants yet tested, Saintpaulia is the only species in which CO₂ concentrations >800 μl·liter⁻¹ did not promote growth and yield of the stock plants. However, higher concentrations within the tested range did not lead to any detectable damage.

Fig. 3. Cutting yields of Chrysanthemum x indicum ‘Trump’ following different CO₂ enrichment levels (μl 1⁻¹ = microliters per liter).

Fig. 4. Cutting yields of Fuchsia x hybrida ‘Hanna’ following different CO₂ enrichment levels (μl 1⁻¹ = microliters per liter).

Fresh and dry weights of cutting. In addition to total cutting yield, the quality of the cuttings is also important. The fresh or dry weight per cutting can be used as an index for cutting quality. Carbon dioxide enrichment promoted the fresh and dry weight per cutting of Pelargonium x zonale ‘Empress’ (Table 1). In addition to increased cutting yields, a dry weight increase of ≈18% was obtained with the CO₂ enrichment of 1600 μl·liter⁻¹, while the fresh weight per cutting increased up to 1200 μl·liter⁻¹ CO₂. No influence of the CO₂ treatment on the weight of the cuttings was found with the Pelargonium cultivar Lachskönigin. The results for Chrysanthemum, Fuchsia, and Saintpaulia again indicate the promoting effect of the CO₂ treatment on cutting fresh and dry weights. Carbon
dioxide enrichment of up to 1600 μl-liter⁻¹ led to the best results for Chrysanthemum and Fuchsia, while 1200 μl-liter⁻¹ was the optimum concentration for Saintpaulia. The increase of fresh weight per cutting was 10% for Chrysanthemum, 8% for Fuchsia, and 20% for Saintpaulia, respectively.

Increase in fresh weight during propagation. Carbon dioxide treatment during stock plant culture had no clear influence on rooting and growth rate of the cuttings harvested from these plants. *Pelargonium x zonale* 'Empress' did not show a significant increase in fresh weight per cutting due to CO₂ enrichment during stock plant cultivation, but CO₂ enrichment during the propagation period led to a marked increase in fresh weight (Fig. 6). The optimum CO₂ concentration was 1200 μl-liter⁻¹, whereas CO₂ enrichment to 1600 μl-liter⁻¹ led to a decrease in fresh weight production. In contrast, cuttings of *Pelargonium x peltatum* from stock plants with CO₂ enrichment showed an increase in fresh weight production during the propagation period (Fig. 7). Again, CO₂ enrichment during propagation enhanced fresh weight up to 1200 μl-liter⁻¹. Similar results were obtained with Chrysanthemum, where CO₂ enrichment during stock plant cultivation led to an increase in the fresh weight of the cuttings during propagation. Carbon dioxide enrichment up to 1200 μl-liter⁻¹ during the propagation period led to a substantial increase in fresh weight per cutting as well (Fig. 8). In the case of *Fuchsia x hybrida* 'Hanna', CO₂ enrichment during stock plant culture had no effect on the subsequent growth of the cuttings (Fig. 9). However, there was again a promoting effect of CO₂ treatment during propagation on cutting fresh weight increase. There was no evident influence of CO₂ treatment during stock plant cultivation on *Saintpaulia ionantha* (Fig. 10). Although the optimum CO₂ concentration for cutting production was 800 μl-liter⁻¹, a CO₂ enrichment of 1200 μl-liter⁻¹ during propagation led to the best results.

### Conclusions

Nurseries in Germany rarely use CO₂ concentrations >800 μl-liter⁻¹ at present; however, the results of these investigations with stock plants make it clear that CO₂ enrichment up to 1200 or 1600 μl-liter⁻¹ improves cutting production and cutting quality. This level is in agreement with the results of Eng et al. (1) and Tsujita (10), who tested the response of Chrysanthemum stock plants to CO₂ enrichment of 1375 and 1300 μl-liter⁻¹, respectively. Research by Moe (7) with Campanula stock plants indicated that a high CO₂ level (~1800 μl-liter⁻¹) was beneficial under low light conditions (2000 lx), whereas the optimum CO₂ concentration dropped with increasing light intensity. The results presented here are confined to those obtained during the winter, with low light intensity. Considering the attainable increase in cutting yield of up to 60%, as the results of Eng et al. (1) and Tsujita (10) confirm, there is no doubt that CO₂ enrichment is economically worthwhile for young-plant nurseries. A further increase in cutting yield and quality might be achieved with supplementary illumination.

### Table 1. Effect of CO₂ enrichment during stock plant cultivation on fresh and dry weight of the cuttings (average of six to 10 harvests).

<table>
<thead>
<tr>
<th></th>
<th><em>Pelargonium x zonale</em> 'Empress'</th>
<th><em>P. x peltatum</em> 'Lachskönigin'</th>
<th><em>Chrysanthemum x indicum</em> 'Trumpf'</th>
<th><em>Fuchsia x hybrida</em> 'Hanna'</th>
<th><em>Saintpaulia ionantha</em> 'Typ 6'</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ enrichment (μl-liter⁻¹)</td>
<td>fresh wt (g)</td>
<td>dry wt (g)</td>
<td>fresh wt (g)</td>
<td>dry wt (g)</td>
<td>fresh wt (g)</td>
</tr>
<tr>
<td>Control</td>
<td>4.01</td>
<td>0.45</td>
<td>3.88</td>
<td>0.39</td>
<td>0.80</td>
</tr>
<tr>
<td>800</td>
<td>4.14</td>
<td>0.45</td>
<td>3.57</td>
<td>0.38</td>
<td>0.83</td>
</tr>
<tr>
<td>1200</td>
<td>4.54</td>
<td>0.48</td>
<td>3.87</td>
<td>0.40</td>
<td>0.84</td>
</tr>
<tr>
<td>1600</td>
<td>4.50</td>
<td>0.53</td>
<td>3.75</td>
<td>0.40</td>
<td>0.88</td>
</tr>
<tr>
<td>LSD 5% level</td>
<td>0.41</td>
<td>0.066</td>
<td>NS</td>
<td>NS</td>
<td>0.05</td>
</tr>
</tbody>
</table>

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An after-effect of the stock plant treatment on propagation success was not evident in all instances, whereas CO₂ enrichment during propagation once again showed distinct benefits. Kobel (5) found that CO₂ treatment of Chrysanthemum stock plants did not promote the rooting of cuttings harvested from these plants, whereas Moe (7) demonstrated a clear influence of CO₂ treatment of Campanula stock plants on the rooting of cuttings and young plant fresh and dry weights. When conducting experiments with CO₂ enrichment, it is important to distinguish between winter and summer growth periods. Carbon dioxide experiments during the summer failed to promote stock plant growth or propagation success. This failure can be attributed to high light intensities, which may overcome the CO₂ effect, and to the short periods each day during which the vents are closed. Thus, under Central European conditions, CO₂ enrichment is limited to the winter (from October to March).

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Stock Plant Lighting and Adventitious Root Formation

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Root formation in cuttings is influenced by the light conditions during the growth of stock plants. Exclusion of light from the entire shoot prior to propagation stimulates the formation of roots in some woody species. Localized etiolation of that part of the stem, which will become the cutting base, also can be effective (9, 14, 15).

In many experiments, it has been determined that changes in stock plant irradiance or photoperiod may affect the subsequent rooting process in cuttings (1). The effect, however, differs from species to species. Additionally, it appears that other factors modify the irradiance response. This review summarizes the effects of stock plant irradiance and photoperiod on adventitious root formation and discusses whether the radiant exposure (light integral) could be the factor ultimately controlling the subsequent rooting process.

IRRADIANCE

Reduction of natural irradiance by shading has been demonstrated to promote the rooting of cuttings. This was obtained in Rhododendron (23) and Dahlia pinnata Cav. (5). Biran and Halevy (5) reported that three different cultivars of Dahlia pinnata reacted differently. Two cultivars had increased rooting percentages after shading treatment. The third cultivar was not significantly affected by the shading treatment.

The effect of different irradiances has been studied in detail in Pisum sativum L. by Hansen and Eriksen (17). A decreasing number of roots was found with increasing irradiance from 7 to 68 W m⁻² (400–700 nm). Similar effects have later been observed in several other genera, such as Hedera (35), Hibiscus (24), Ligustrum (26), Picea (10), Pinus (19, 40), Populus (12), and Rhododendron (11).

A number of plant species have shown the opposite response. In Campanula isophylla Moretti (30) and Chrysanthemum × morifolium Ramat. (7, 13), the number of roots was increased with increasing irradiance. The experiment by Weigel et al. (43) with a different Chrysanthemum × morifolium cultivar, however, showed a reduction in root number with increasing irradiance. Whether this result is attributable to the different cultivar or other factors is not known. Enhanced root formation was also obtained in Vigna radiata (L.) R. Wilcz. when the stock plants had been grown at a high irradiance of 80 W m⁻² (400–750 nm) compared with 18 W m⁻² (22). Furthermore, an increase in root number with increasing irradiance or supplementary lighting has been obtained with Begonia × elatior (L. Bertram, personal communication).

A number of investigations that have dealt with the effects of stock plant irradiance on subsequent root formation in cuttings are listed in Table 1. This list comprises only a limited number of plant species, but it indicates that most of the species investigated so far produce fewer roots and/or have a reduced rooting percentage with increasing stock plant irradiance.

MODE OF IRRADIANCE ACTION

It is unknown why some species produce more roots with increasing irradiance and why other species produce fewer roots. It is also unknown why different cultivars of the same species react differently. Thus, a general explanation is not possible. Scientists can only speculate of several possible irradiance effects on the stock plant that may subsequently influence the rooting process. Therefore, it may be more valuable to evaluate some of the few experiments that have investigated the modifying effect of different factors on the irradiance response.

In the Pisum sativum rooting system, Veierskov et al. (42) demonstrated that the cotyledons played an important role during the first 11 days of stock plant growth (Fig. 1). Removal of cotyledons resulted in a reduction in stock plant growth, and the cuttings, which were excised 11 days after sowing, produced fewer roots than cuttings from intact stock plants. The interesting observation was, however, that the removal of cotyledons strongly affected the type of irradiance response. Whereas no removal or removal a few days before cuttings were excised resulted in cuttings that showed the typical pea-type response (17), opposite irradiance responses were observed with cuttings from stock plants that had their cotyledons removed before the eighth day (Fig. 1).

These results suggest that one or more compounds, which are supplied by the cotyledons, interact with the stock plant irradiance.

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