HORTICULTURE RESEARCH INTERNATIONAL

EFFORD

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CONTRACT REPORT

Pot Plants: Optimisation of light intensity and CO_2 utilization for Christmas Production

Undertaken for
Electricity Association Technology Ltd
1992

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AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

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RELEVANCE TO GROWERS AND PRACTICAL APPLICATION

Application

The use of two light intensities with and without supplementary CO_2 were compared for improving production of Rieger Begonias for the Christmas market. An economic appraisal was carried out on the use of the lighting.

Summary

During the winter months it becomes increasingly difficult to produce high quality plants and the time to marketing becomes longer. In previous trials at Lee Valley E.H.S. and HRI Efford, the use of supplementary lighting has been shown to enhance growth and flowering in pot plants. Similar effects have been found with CO_2 enrichment, (see Grower 2 November 1989), but the response of crops to CO_2 has been variable. Therefore the use of supplementary lighting and CO_2 levels need further investigation to examine the degree of improvement possible in the production of quality plants in the winter. Rieger Begonia is regarded as a useful indicator plant to examine the effects of these two factors.

The range of begonia cultivars selected fell into three groups. These were :

Rosalie types:	Orania, Rosanna, Anja, Marinella
Arosa types:	Karin, Nelson
Ilona types:	Ilona, Netja

These were subjected to the following cultural conditions after potting in weeks 40 and 41.

1. 2500 lux SON/T supplementary lighting with 3-fold CO_2 enrichment
2. 2500 lux SON/T supplementary lighting with ambient CO_2 levels
3. 4000 lux SON/T supplementary lighting with 3-fold CO_2 enrichment
4. 4000 lux SON/T supplementary lighting with ambient CO_2 levels

The response to the combinations of light and CO_2 levels were variable between the different types of begonia, and occasionally between cultivars in the same group. There were, however, some distinct trends.

The average marketing date for all treatments fell within week 51, with those lit at 4000 lux approximately two days earlier than those lit at 2500 lux. There was a small delay in flowering as a result of CO_2 enrichment.

There was a strong interaction between light and CO_2 such that at 2500 lux, CO_2 enrichment had no influence on plant size, though quality was slightly improved in Netja and the Rosalie cultivars, but at 4000 lux additional CO_2 increased growth.

In general, plants grown under 4000 lux were more compact than at 2500 lux and considered to be of better quality. The addition of CO_2 at 4000 lux, therefore, though increasing growth, actually reduced overall quality for Arosa and Ilona type Begonias.

The effect of the light CO_2/light interaction could be explained in part by light being the limiting factor at the lower intensity with plants stretching as a consequence, whereas at 4000 lux CO_2 could be the limiting factor, hence the response to additional CO_2 observed.

While 4000 lux was considered to produce the best quality plants, the costs of such a treatment needs to be taken into account. It is accepted that quality Rieger Begonias cannot be produced in the winter without supplementary lighting, but whether the potential increased returns from a Christmas market are economic was examined in an economic appraisal. It was concluded that if a premium return of £1.50 per plant could be obtained then the 4000 lux could be economically viable. This would limit its use to production for the Christmas market where such prices are possible. However, since reasonable quality was also obtained at 2500 lux it might be more economic to produce under this regime and improve quality through the addition of CO_2.

EXPERIMENTAL SECTION

INTRODUCTION

During the winter months it becomes increasingly difficult to produce high quality plants and the time to marketing becomes longer. In previous trials at Lee Valley E.H.S. and HRI Efford, the use of supplementary lighting has been shown to enhance growth and flowering in pot plants. Similar effects have been found with CO_2 enrichment, (see Grower 2 November 1989), but the response of crops to CO_2 has been variable. Therefore the use of supplementary lighting and CO_2 levels need further investigation to examine the degree of improvement possible in the production of quality plants in the winter. Rieger Begonia is regarded as a useful indicator plant to examine the effects of these two factors.

MATERIALS AND METHODS

Site

The plants were grown on benches on capillary matting in four compartments of the multifactorial glasshouse K block, each compartment having a separate treatment.

Treatments

Cultivars :

Eight cultivars of Rieger Begonia.	Ilona types:	Ilona
		Netja
	Rosalie type:	Orania
		Rosanna
		Anja
		Marinella
	Arosa type:	Nelson
		Karin

Due to an accident during transit plants for the trial were delivered on two dates:

Royal Eveleens:	Week 40	Varieties:	Marinella
			Anja
			Orania
			Rosanna
Gasa (Kaermose Nursery):	Week 41	Varieties:	Karin
			Ilona
			Netja
			Nelson

Supplementary Lighting:	(i) 2500 lux SON/T
	(ii) 4000 lux SON/T
CO_2	(i) Ambient
	(ii) x 3 fold enrichment (1000 ppm)

Design

Rosalie types:	4	main plots (2 lighting x 2 CO_2)
	x	
	12	sub plots (4 cultivars x 3 replicates)
	48	plots in total
Ilona and Arosa types:	4	main plots (2 lighting x 2 CO_2)
	x	
	24	sub plots (4 cultivars x 6 replicates)
	96	plots in total

Plot Size: 6 recorded plants + 2 guards at either end of the row.

Layout: The trial was divided into two randomised blocks within each main plot of lighting and CO_2 level. These blocks were:

(i) Rosalie types (delivered week 40)
(ii) Ilona and Arosa types (delivered week 41)
(Appendix I, page 26)

Cultural Details

On arrival the plants were potted into 13 C terracotta pots using Fison's Levington M2. The plants were given a post potting spray of iprodione as Rovral (lg/l) against *Botyrtis*. A treatment of the parasitic nematode *Steinernema feltiae* was applied as Nemasys on 13.10.93 to control Sciarid fly (*Lycoriella* sp).

The plants were given 18 hour days from potting to 18.10.92 with supplementary lighting using high pressure sodium lamps (SON/T). This was reduced to 12 hours on 19.10.92 for three weeks to provide short days to initiate flowers. The daylength was then increased in 16 hours until marketing.

Temperatures were kept at 20°C (venting at 22°C) from potting to 5.10.92 and then reduced to 18°C (venting at 20°C) for the rest of the crop.

Liquid feeding commenced on 19.10.92 and occurred at every watering until 30.11.93. The feed supplied 100 ppm N, 50 ppm P_2O_5 and 100 ppm K_2O.

The stock solution comprised:

	g/l
Potassium Nitrate	45
Ammonium Nitrate	35
Monoammonium Phosphate	17

Diluted 1 in 200
pH adjusted to 5.5 to 6.

The plants, initially pot thick on the benches, were spaced to 18 plants per m^2.

Growth control was achieved through the application of chlormequat 46% (Cycocel at 1.5 ml/l plus 0.1 ml/l Agral wetter). This was applied to the Rosalie types on 3.11.92 and to Anja on 7.12.92.

Early unwanted flowers were removed on 2.11.92, 18.11.92 and 4.12.92.

A drench of furalaxyl as Fongarid (2g/l) was applied on 31.10.92.

Assessments

At Marketing:

1. Plant height (mm)
2. Plant spread at the widest point (mm)
3. Plant spread at 90° to the widest point (mm)
4. Number of open flowers
5. Number of coloured buds
6. Quality (1 being worst, 3 being best) (see Plates 1 and 2, Appendix III, page 37)

Statistical analysis was carried out on these results with the Rosalie results being analysed separately from the Ilona and Arosa results due to the different start dates.

RESULTS

The pattern of plant scores was variable between the groups of Begonia and sometimes between cultivars within one group. The differences commented upon here are those shown to be significantly different (see Tables 2 to 8, Appendix II, pages 30 to 36).

Mean Height

Rosalie type: When grown at 2500 lux only Anja showed a response to increased CO_2 levels through increased height, while at 4000 lux Marinella and Anja were smaller with additional CO_2 than without (Table 2, Appendix II, page 30).

At ambient CO_2 levels no difference in height was seen between plants grown at 2500 or 4000 lux, however, where additional CO_2 was provided those Anja plants grown at 2500 lux were taller.

No overall pattern was seen across the cultivars (Fig 1, page 13).

Arosa type: The two cultivars in this group reacted differently to the light and CO_2 levels. When grown at 2500 lux Karin was taller at ambient CO_2 levels, while at 4000 lux the addition of CO_2 increased plant height. Nelson only showed an increase in height with additional CO_2 when grown at 2500 lux (Table 2, Appendix II, page 30).

High light levels (4000 lux) gave taller plants of Karin when CO_2 was added, but at ambient CO_2 levels 2500 lux gave taller plants. Light levels only appeared to influence the growth of Nelson at ambient CO_2 levels, where the higher light level gave taller plants.

Ilona type: The addition of CO_2 had no effect on plant height at 2500 lux, but produced taller plants when they were lit at 4000 lux (Table 2, Appendix II, page 30).

At ambient CO_2 levels plants grown at 2500 lux were taller than those at 4000 lux, however, with the addition of CO_2 only Netja was taller at 2500 lux.

Overall those plants grown at 4000 lux with ambient CO_2 were shorter than those grown under other treatments (Fig 1, page 13).

Mean Overall Spread

Rosalie type: When the plants were grown at 2500 lux the addition of CO_2 made no difference to overall plant spread, but at the higher light level of 4000 lux Anja and Rosanna increased their spread with supplementary CO_2 (Table 3, Appendix II, page 31). A similar pattern of results seen with Orania and Marinella did not prove to be significant.

Plants grown at ambient CO_2 levels were all broader at 2500 lux compared to 4000 lux, while with additional CO_2 the light intensity did not affect the plant spread.

Plants grown at 4000 lux with ambient CO_2 had the smallest overall spread (Fig 2, page 14).

Arosa type: Additional CO_2 only increased the plant spread when they were grown at 4000 lux, no effect being seen at 2500 lux (Table 3, Appendix II, page 31).

When grown at ambient CO_2 levels plants grown at 2500 lux had a greater spread than those at 4000 lux, however, with supplementary CO_2 Karin was broader at 4000 lux.

Plants grown at 4000 lux with ambient CO_2 levels had the smallest overall spread. (Fig 2, page 14).

Ilona type: As for the Arosa types extra CO_2 increased plant spread at 4000 lux, with no effect at 2500 lux. At ambient CO_2 levels the plants grown at 2500 lux were wider than those at 4000 lux, while light levels made no difference to plant spread at high CO_2 levels. (Table 3, Appendix II, page 31).

Plants grown at 4000 lux with ambient CO_2 levels had the smallest overall spread (Fig 2, page 14).

Mean Number of Open Flowers

Rosalie type: When grown at 2500 lux additional CO_2 produced more flowers on Orania, while at 4000 lux extra CO_2 actually produced fewer flowers on Marinella, Orania and Rosanna (Table 6, Appendix II, page 34). Anja plants followed a similar pattern to Orania, but this did not prove to be significant.

At ambient CO_2 levels the higher light level (4000 lux) increased flower production on Marinella, Orania and Rosanna, while at high levels of CO_2 light levels made no difference to flower numbers.

Overall plants grown at 4000 lux with ambient CO_2 levels had more flowers (Fig 3, page 15).

Arosa type: At 2500 lux additional CO_2 did not effect flowering levels, while at 4000 lux Nelson produced more flowers at ambient CO_2 levels (Table 6, Appendix II, page 34).

At ambient CO_2 levels both cultivars in this trial produced more flowers with 4000 lux, however, with additional CO_2 only Karin produced more at the higher light level.

Overall plants grown at 4000 lux had more flowers than those grown at 2500 lux (Fig 3, page 15).

Ilona type: The level of CO_2 did not affect the number of flowers on these begonias, but 2500 lux produced more flower on Netja than 4000 lux regardless of CO_2 levels (Table 6, Appendix II, page 34).

No overall pattern in number of flowers was visible (Fig 3, page 15).

Mean Number of Coloured Buds

Rosalie type: When plants were grown at 2500 lux the level of CO_2 made little difference to the number of buds present, however at 4000 lux ambient CO_2 levels gave more buds on all cultivars, but this only proved significant for Orania and Rosanna (Table 7, Appendix II, page 35).

At ambient CO_2 levels the higher light level increased bud numbers on Marinella, Orania and Rosanna, but light level made little difference when extra CO_2 was present.

Overall 4000 lux at ambient CO_2 levels gave most coloured buds (Fig 4, page 16).

Arosa type: At 2500 lux Karin produced more buds with additional CO_2, however, at 4000 lux the level of CO_2 had no effect on bud number (Table 7, Appendix II, page 35).

Light levels did not appear to effect the number of buds present on the plant.

Overall, there was very little difference between treatments in the number of coloured buds (fig 4, page 16).

Ilona type: Netja produced more buds at ambient CO_2 levels when grown at 2500 lux, but Ilona produced more with supplementary CO_2 at 4000 lux light intensity. Light levels had no effect on the number of buds present (Table 7, Appendix II, page 35).

No clear pattern in bud numbers was seen in the Ilona types (Fig 4, page 16).

Mean Quality Score

The plants produced in all treatments were of marketable quality.

Rosalie type: At 2500 lux CO_2 levels had no significant effect on plant quality however, at 4000 lux, quality was improved by the addition of supplementary CO_2 for Marinella and Anja (Table 8, Appendix II, page 36). Orania also followed this trend but the result was not significant.

At ambient CO_2 levels Rosanna was of better quality under 4000 rather than 2500 lux while with supplementary CO_2 Anja and Orania also produced better quality plants at 4000 lux. Marinella produced similar, although not significant results.

Overall plants grown at 4000 lux with supplementary CO_2 were the best quality (see Fig 5, page 17).

Arosa type: The addition of CO_2 reduced plant quality at 4000 lux, but had no effect at 2500 lux. At ambient CO_2 levels lighting to 4000 lux compared to 2500 lux improved quality (Table 8, Appendix II, page 36).

Overall plants grown at 4000 lux at ambient CO_2 levels were of the best quality (see Fig 5, page 17).

Ilona type: Additional CO_2 only improved the quality of Netja when grown at 2500 lux. Plants grown at 4000 lux had better quality at ambient CO_2 levels (Table 8, Appendix II, page 36).

The higher level of supplementary lighting benefited quality at ambient CO_2 levels, but similar results were obtained at both light levels where CO_2 enrichment was introduced.

Overall plants grown at 4000 lux at ambient CO_2 levels were of the best quality (Fig 5, page 17).

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Fig 1

Pot Plants : Light / CO_2 Optimisation

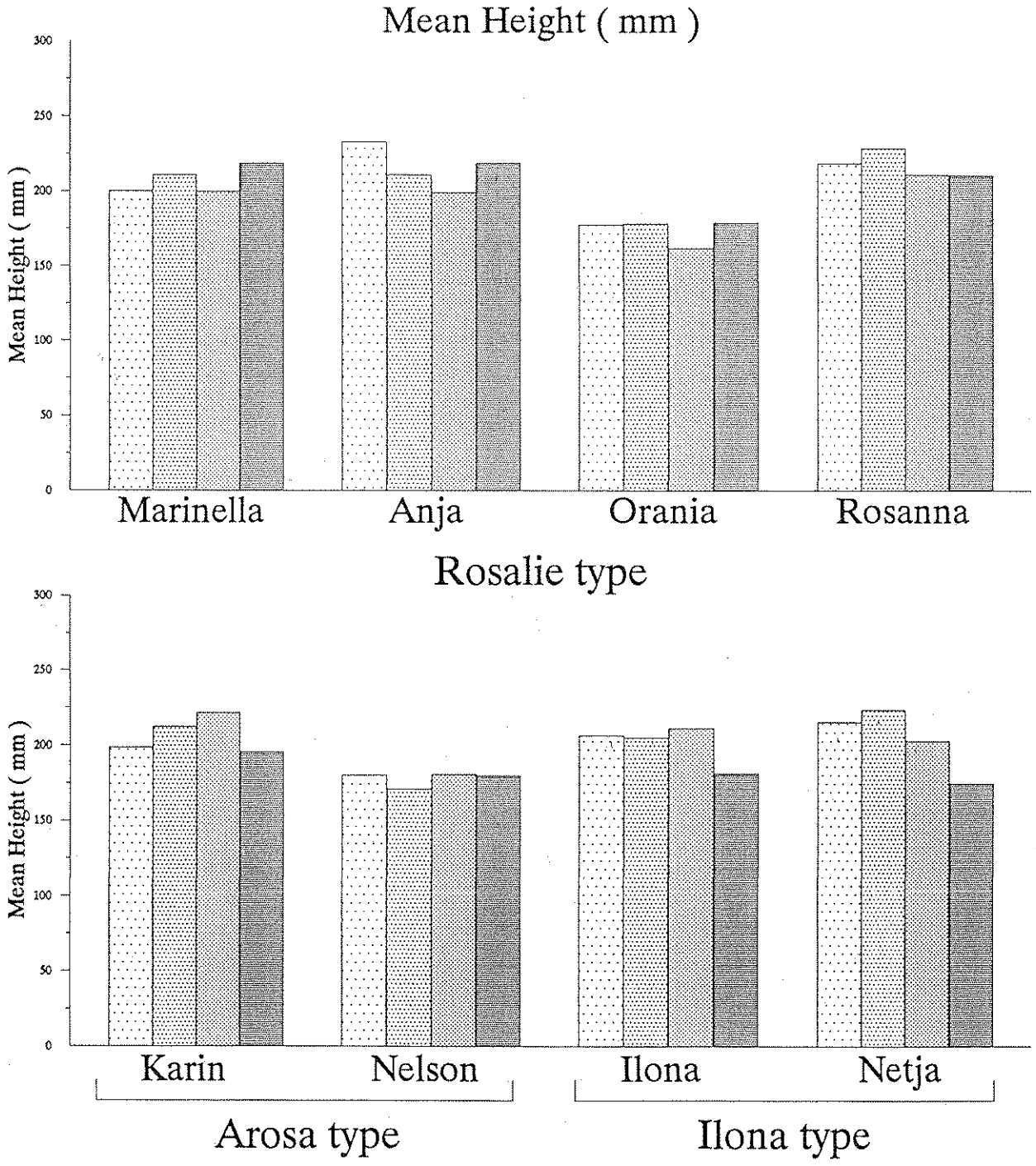

Fig 2

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Pot Plants : Light / CO_2 Optimisation

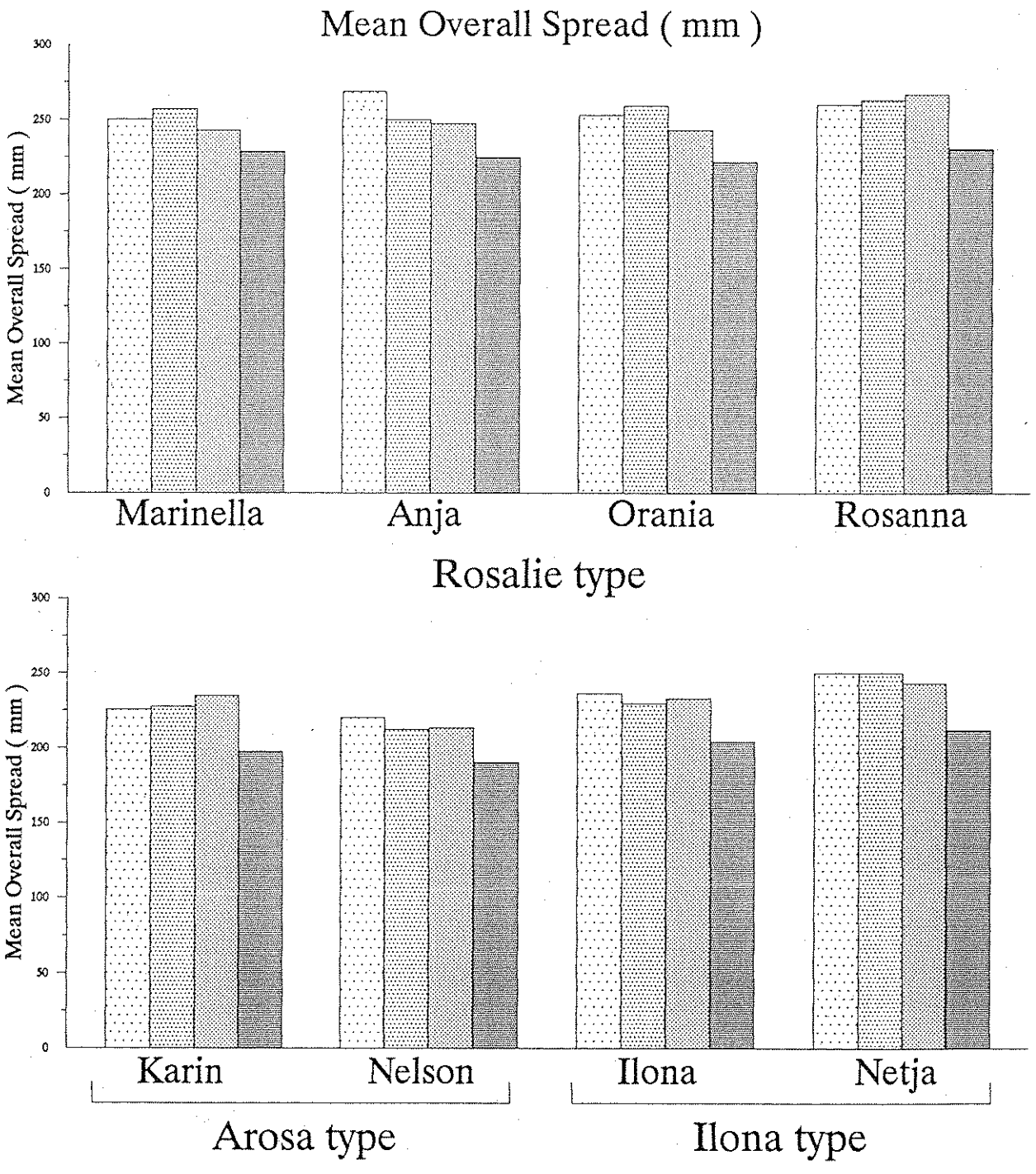

Fig 3

Electricity Association Technology Ltd.
Pot Plants : Light / CO_2 Optimisation

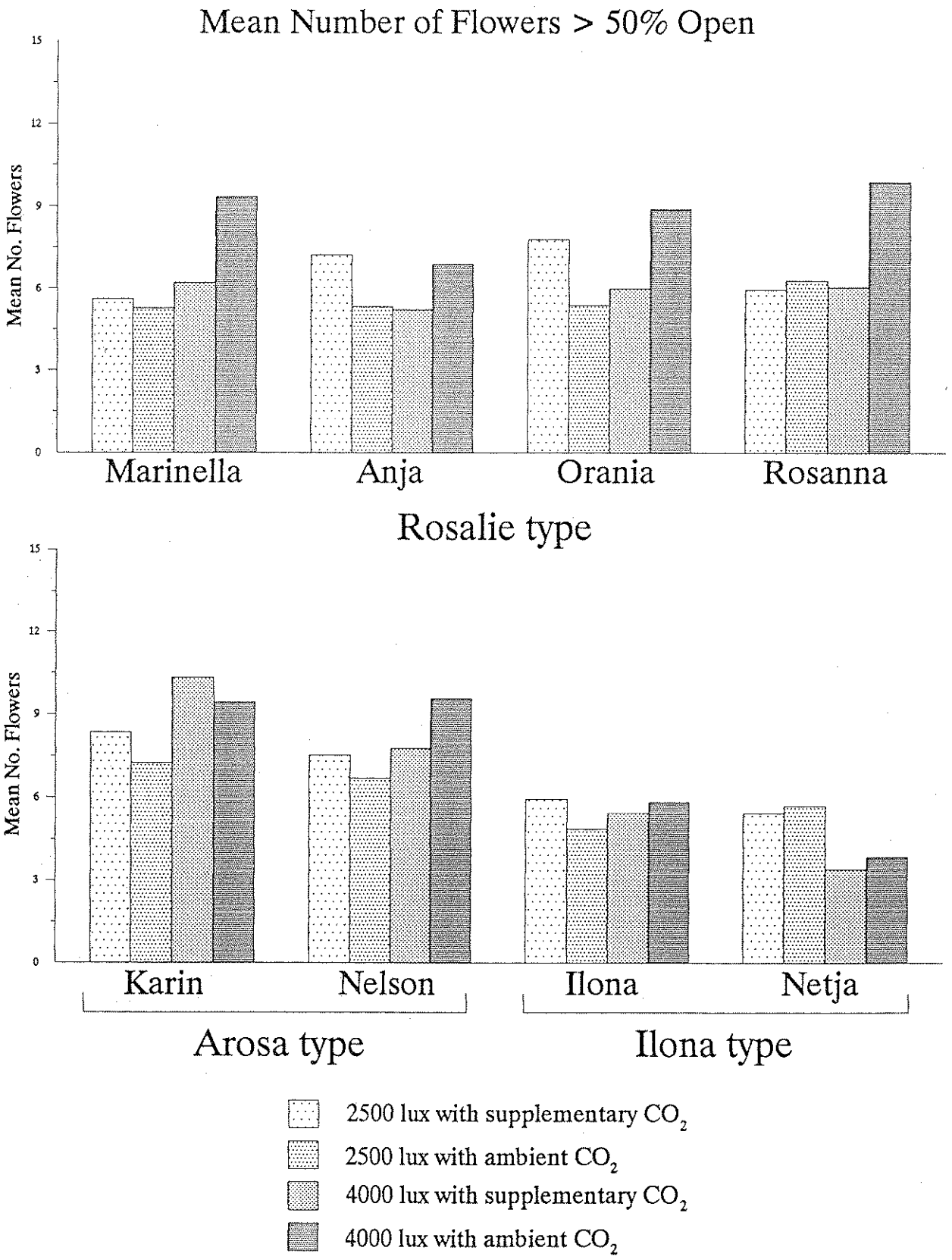

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Fig 4

Pot Plants : Light / CO_2 Optimisation

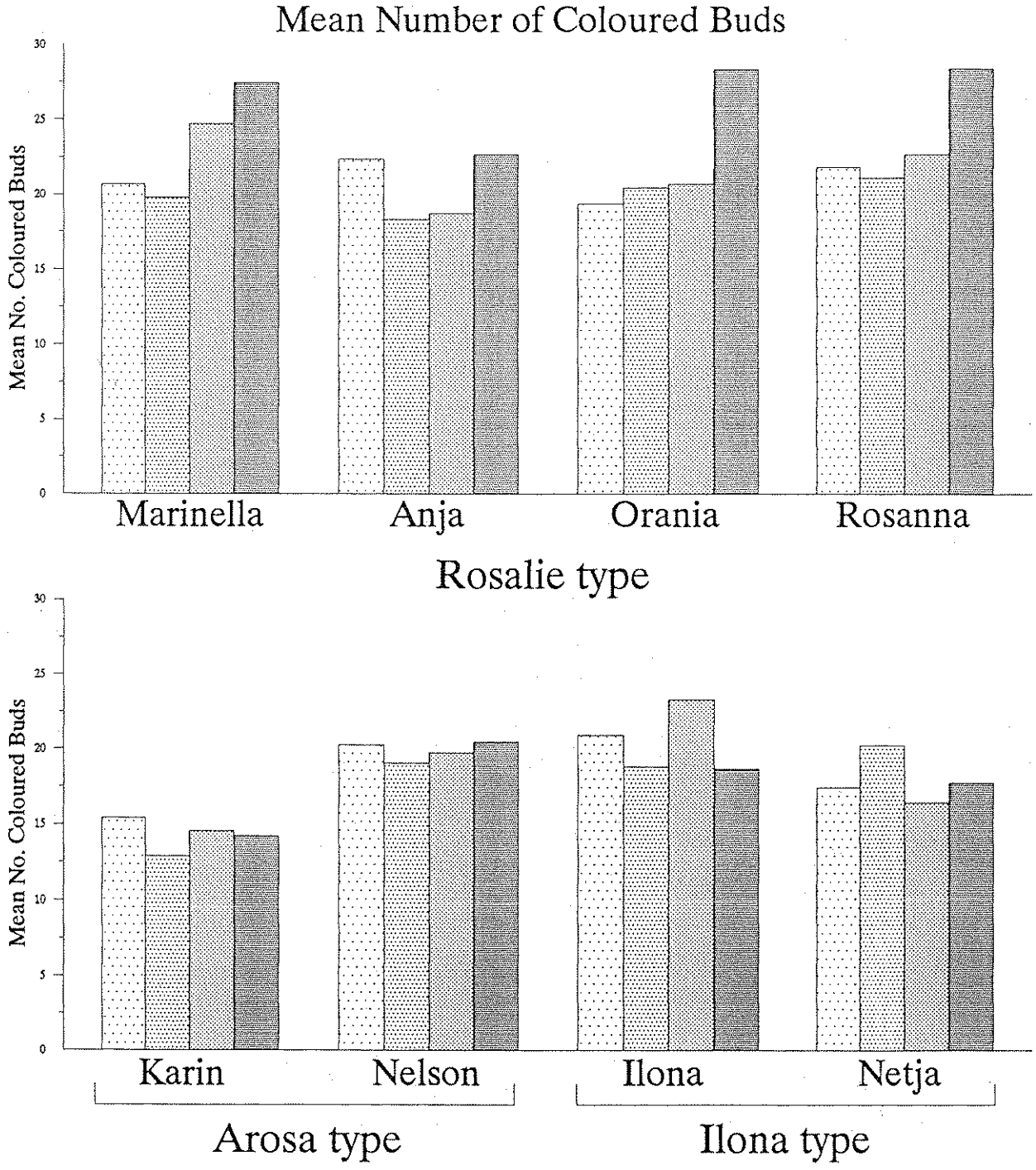

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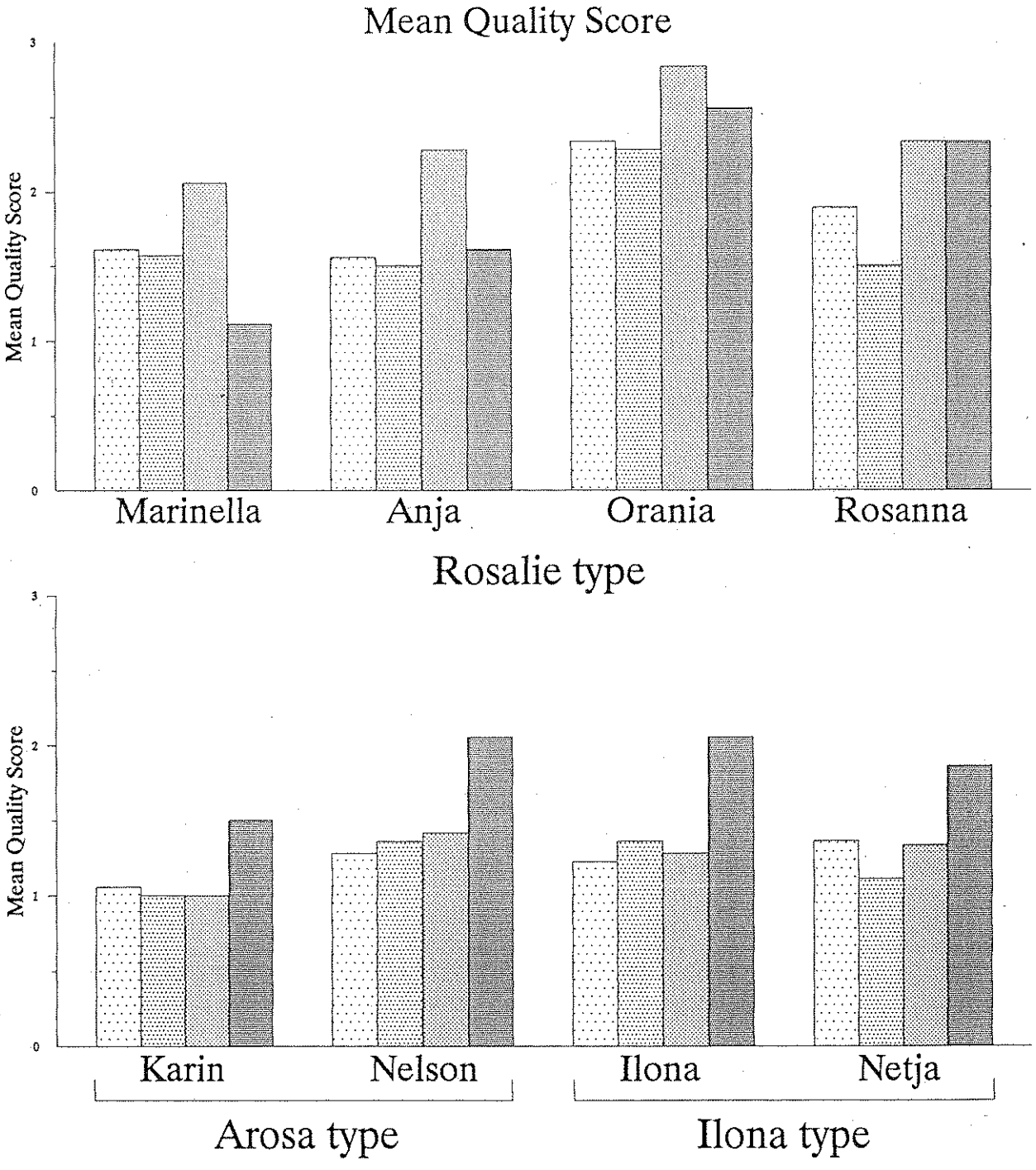
Fig 5

Pot Plants : Light / CO_2 Optimisation



Summary of Plant Scores

Comparison of Light Level

(i) **At Ambient CO_2 levels :** Plants grown at 2500 lux were broader than those at 4000 lux and in the Ilona type plants were also taller. Plants grown at 4000 lux were of higher quality than those at 2500 and in the Rosalie type had a higher number of buds.

(ii) **At 3-fold CO_2 levels :** There was no clear cut response to different light levels in terms of plant height and spread or number of buds present. Only the Rosalie types tended to have a better quality at 4000 lux rather than 2500 lux. Light level had no effect on the quality of the other begonia types.

Comparison of CO_2 level

(i) **At 2500 lux :** Overall, additional CO_2 did not alter the plant size or the number of buds present, however, one cultivar in the Ilona group and the Rosalie cultivars showed a tendency for improved quality with supplementary CO_2, although in the latter this did not prove significant.

(ii) **At 4000 lux :** All cultivars increased their overall spread with supplementary CO_2 and the Arosa and Ilona types had a tendency to be taller, although, the latter effect was coupled with a decrease in quality. The Rosalie types tended to be smaller with supplementary CO_2 with fewer buds but an improved plant quality.

See Plates 3 to 10, Appendix III, page 38.

Mean Marketing Date

The variation in marketing date between treatments was small. The use of 4000 lux reduced time to marketing by approximately 2 days compared with 2500 lux, while the addition of CO_2 increased the time to marketing by less than 1 day on average (Table 1).

Table 1 Mean Marketing Date

	Date (December)
2500 lux + CO_2	19
2500 lux	18
4000 lux + CO_2	16
4000 lux	16

Economic Appraisal of Lighting

Prices supplied by John Weir of Electricity Association Technology Ltd.

1. Annual Capital Investment per lamp

Cost of Luminaire	£ 90.00
Cost of Lamp	£ 30.00
Cost of Installation	£ 50.00
Total per lamp	£170.00

Assuming a relamping period of 8 years:

£170.00 ÷ 8

= £ 21.25 per lamp per year

2. Annual Interest per lamp

Assuming the £170.00 per lamp is borrowed and paid off over an 8 year period:

Interest will be a variable sum over the 8 years, however, the average amount outstanding per lamp = £170.00 ÷ 2

= £ 85.00

∴ the average interest per year is the interest on £85.00

Taking an interest rate of 12% the annual interest would be:

$$\frac{£85.00 \times 12\%}{100}$$

= £10.20 per lamp per year

3. Annual Running Costs

Based on 1300 burning hours per year. This is the number of lighting hours required for 1 crop assuming the lamps run continuously. This may be reduced by turning off lamps during bright periods.

Luminaire wattage : 0.453 kw

Price per kw hour : £0.06

To consume 1 kw hour of electricity the lamps need to be on for $\frac{1}{0.453}$ = 2.208 hours

∴ Every 2.208 hours cost £0.06

∴ 1300 hours cost £35.33 per lamp per year

4. Annual Maintenance Costs

Maintenance costs per lamp over 8 years = £2.00

∴ cost per lamp per year = £0.25

Total Annual Cost per lamp : £21.25 + £10.20 + £35.33 + £0.25

= £67.03

Lighting to 2500 lux

Area of compartment : 402 m^2

Number of lamps required : 33

∴	Total annual cost	=	£2211.99
	Total annual cost per m^2	=	£2211.99 ÷ 402 m^2
		=	£5.50 per m^2

∴ ***Cost per plant :***

Spacing	*Cost*
18 plants/m^2	*£0.31*
25 plants/m^2	*£0.22*

Lighting to 4000 lux

Area of compartment : 402 m^2

Number of lamps required : 52

∴	Total annual cost	=	£3485.56
	Total annual cost per m^2	=	£3485.56 ÷ 402 m^2
		=	£8.67 per m^2

∴ ***Cost per plant*** :

Spacing	*Cost*
18 plants/m^2	*£0.48*
25 plants/m^2	*£0.35*

The Christmas premium on Rieger Begonia plants which may boost the price up to around £1.50 per plant may absorb the extra cost of production at this time of year.

DISCUSSION

This trial investigated the potential benefits of using different light levels with and without supplementary CO_2 in the production of pot plants for the Christmas market. The range of Rieger Begonias, including cultivars from the Ilona, Rosalie and Arosa groups, used in the trial showed a variable response to the different cultural conditions, however, some general trends could be seen.

The two variable factors in the trial, CO_2 and light, interacted so that the benefits afforded by a particular light level were only seen at a certain CO_2 level. When comparing the plants grown at 2500 lux with those at 4000 lux at ambient CO_2 levels the former were significantly larger, while the latter were more compact plants of a higher quality. These differences were much less obvious when supplementary CO_2 was added during culture, especially in terms of plant size. However, the quality of the Rosalie cultivars was still slightly better at 4000 rather than 2500 lux. The addition of CO_2 at 4000 lux lighting increased the plant size, in particular plant spread, to the equivalent of those grown at 2500 lux, but with Ilona and Arosa types this was accompanied by a reduction in quality. The addition of CO_2 to 2500 lux lighting did not affect plant size, but tended to slightly improve overall plant quality in Netja and the Rosalie cultivars, although the latter was not significant.

The size differences between treatments may be explained in part by 2500 lux being sub-optimal, causing more stretching of the Rieger Begonias both in height and spread. As CO_2 is not limiting, additional CO_2 caused no size increase, but some improvement in quality.
At 4000 lux the plant would not need to stretch to optimise light capture as CO_2 would be a limiting factor. Once extra CO_2 is added light may again become limiting and the plant would stretch, increasing plant size.

There appears to be a link between increased height and reduced quality which may be explained by this stretching. The plant quality score was partially based upon the compactness of the plant and as seen from Plate 2 of Nelson (page 37) showing example quality score plants, the lowest quality plant looks more leggy with a lot of stem and petiole showing. This could be the effect of stretching.

Lighting to 2000 lux and 4000 lux would add 22p and 35p respectively to the price of each plant with 25 pots per m^2. These would both be economically viable assuming the plants would achieve a Christmas premium boosting the basic price of Begonias to £1.50 per plant. The variation in response to light levels between cultivars and the fact that the plants produced at 2500 lux were all of marketable quality would advocate the use of 2500 lux rather than 4000 lux for a mixed cultivar crop to maximise returns. If, however, optimum quality was required, 4000 lux would be better, but only if the CO_2 level could be optimised for the particular type of begonia being grown. From the results of this trial, the Arosa and Ilona types, for example, were of no better quality at 4000 than at 2500 lux if CO_2 was added, while with the Rosalie types CO_2 enrichment produced the best quality. A small difference was seen in marketable dates, however, whether the decrease of two days to marketing when raising the light level from 2500 to 4000 lux is significant in terms of production schedules is debatable. The addition of CO_2 appeared to have every little effect on the time to marketing.

CONCLUSIONS

Light and CO_2 interact, so the two factors have to be looked at in combination to establish the best cultural conditions, which varied with cultivar grouping.

- Plants produced in all treatments were of marketable quality.

- At ambient CO_2 levels 2500 lux produced larger plants than 4000 lux, but of lower quality.

- CO_2 enrichment improved quality of plants grown at 2500 lux to some extent, but its main effect was to increase plant size at 4000 lux, accompanied by a reduction in quality in the case of Ilona and Arosa Begonias.

- Plants grown at 4000 lux flowered on average two days earlier than those under 2500 lux. CO_2 had minimal effect on time of flowering.

- The economic appraisal into the two lighting levels showed 2500 lux at 25 plants/m^2 to cost 22p per plant and 4000 lux to cost 35p per plant. These costs might be absorbed by the potentially higher Christmas prices.

- From the results of this trial lighting to 2500 lux with supplementary CO_2 would appear to be the best option to produce marketable mixed cultivar Rieger Begonias, while maximising returns.

Appendix I

Electricity Association Technology Ltd.
Pot Plants : Light / CO_2 Optimisation

2500 lux with 3-fold CO_2

Rosalie types

	Plot No.	Cultivar	
	X X X X X X X X		
Rep I	X	1	E X
	X	2	G X
	X	3	H X
	X	4	J X
Rep II	X	5	H X
	X	6	J X
	X	7	G X
	X	8	E X
Rep III	X	9	G X
	X	10	J X
	X	11	E X
	X	12	H X
	X X X X X X X X		

Cultivars

E = Marinella

G = Anja

H = Orania

J = Rosanna

Plot = XOOOOOOX

X = guard plant

O = recorded plant

Ilona & Arosa types

	Plot No.	Cultivar	
	X X X X X X X X		
Rep I	X	13	A X
	X	14	B X
	X	15	C X
	X	16	D X
Rep II	X	17	C X
	X	18	B X
	X	19	A X
	X	20	D X
Rep III	X	21	B X
	X	22	C X
	X	23	D X
	X	24	A X
Rep IV	X	25	C X
	X	26	B X
	X	27	D X
	X	28	A X
Rep V	X	29	D X
	X	30	C X
	X	31	B X
	X	32	A X
Rep VI	X	33	B X
	X	34	C X
	X	35	D X
	X	36	A X
	X X X X X X X X		

Cultivars

Arosa type

A = Karin

B = Nelson

Ilona type

C = Ilona

D = Netja

Appendix I

Electricity Association Technology Ltd.
Pot Plants : Light / CO_2 Optimisation

2500 lux with Ambient CO_2

Rosalie types

	Plot No.	Cultivar
	X X X X X X X X	
Rep I	X 37	H X
	X 38	E X
	X 39	J X
	X 40	G X
Rep II	X 41	E X
	X 42	G X
	X 43	J X
	X 44	H X
Rep III	X 45	H X
	X 46	G X
	X 47	E X
	X 48	J X
	X X X X X X X X	

Cultivars

E = Marinella

G = Anja

H = Orania

J = Rosanna

Plot = XOOOOOOX

X = guard plant

O = recorded plant

Ilona & Arosa types

	Plot No.	Cultivar
	X X X X X X X X	
Rep I	X 49	B X
	X 50	C X
	X 51	D X
	X 52	A X
Rep II	X 53	D X
	X 54	C X
	X 55	A X
	X 56	B X
Rep III	X 57	C X
	X 58	D X
	X 59	A X
	X 60	B X
Rep IV	X 61	A X
	X 62	C X
	X 63	B X
	X 64	D X
Rep V	X 65	B X
	X 66	A X
	X 67	C X
	X 68	D X
Rep VI	X 69	C X
	X 70	D X
	X 71	B X
	X 72	A X
	X X X X X X X X	

Cultivars

Arosa type

A = Karin

B = Nelson

Ilona type

C = Ilona

D = Netja

Appendix I

Electricity Association Technology Ltd.
Pot Plants : Light / CO_2 Optimisation

4000 lux with 3-fold CO_2

Rosalie types

	Plot No.	Cultivar
	X X X X X X X X	
Rep I	X 73	J X
	X 74	E X
	X 75	G X
	X 76	H X
Rep II	X 77	H X
	X 78	G X
	X 79	E X
	X 80	J X
Rep III	X 81	E X
	X 82	G X
	X 83	J X
	X 84	H X
	X X X X X X X X	

Cultivars

E = Marinella

G = Anja

H = Orania

J = Rosanna

Plot = XOOOOOOX

X = guard plant

O = recorded plant

Ilona & Arosa types

	Plot No.	Cultivar
	X X X X X X X X	
Rep I	X 85	C X
	X 86	D X
	X 87	B X
	X 88	A X
Rep II	X 89	B X
	X 90	C X
	X 91	D X
	X 92	A X
Rep III	X 93	C X
	X 94	D X
	X 95	A X
	X 96	B X
Rep IV	X 97	A X
	X 98	D X
	X 99	C X
	X 100	B X
Rep V	X 101	C X
	X 102	B X
	X 103	A X
	X 104	D X
Rep VI	X 105	C X
	X 106	A X
	X 107	B X
	X 108	D X
	X X X X X X X X	

Cultivars

Arosa type

A = Karin

B = Nelson

Ilona type

C = Ilona

D = Netja

Appendix I

Electricity Association Technology Ltd.
Pot Plants : Light / CO_2 Optimisation

4000 lux with Ambient CO_2

Rosalie types

	Plot No.	Cultivar
	X X X X X X X X	
Rep I	X 109	H X
	X 110	G X
	X 111	E X
	X 112	J X
Rep II	X 113	E X
	X 114	J X
	X 115	G X
	X 116	H X
Rep III	X 117	G X
	X 118	J X
	X 119	H X
	X 120	E X
	X X X X X X X X	

Cultivars

E = Marinella

G = Anja

H = Orania

J = Rosanna

Plot = XOOOOOOX

X = guard plant

O = recorded plant

Ilona & Arosa types

	Plot No.	Cultivar
	X X X X X X X X	
Rep I	X 121	D X
	X 122	A X
	X 123	B X
	X 124	C X
Rep II	X 125	B X
	X 126	C X
	X 127	D X
	X 128	A X
Rep III	X 129	C X
	X 130	D X
	X 131	B X
	X 132	A X
Rep IV	X 133	B X
	X 134	D X
	X 135	C X
	X 136	A X
Rep V	X 137	C X
	X 138	B X
	X 139	D X
	X 140	A X
Rep VI	X 141	D X
	X 142	B X
	X 143	A X
	X 144	C X
	X X X X X X X X	

Cultivars

Arosa type

A = Karin

B = Nelson

Ilona type

C = Ilona

D = Netja

Appendix II

Table 2 **Mean Height (mm) at marketing**

Cultivar	CO_2 level	Light Level 2500 lux	Light Level 4000 lux
Rosalie types			
Marinella	+ CO_2	199.7	199.4
	- CO_2	210.3	218.1
Anja	+ CO_2	232.2	198.6
	- CO_2	210.3	218.1
Orania	+ CO_2	177.2	161.7
	- CO_2	177.8	178.6
Rosanna	+ CO_2	218.1	211.1
	- CO_2	228.3	210.6
Arosa types			
Karin	+ CO_2	198.5	221.4
	- CO_2	212.2	195.3
Nelson	+ CO_2	180.3	180.8
	- CO_2	171.0	179.9
Ilona types			
Ilona	+ CO_2	206.4	211.3
	- CO_2	204.7	181.1
Netja	+ CO_2	215.1	202.9
	- CO_2	223.2	174.6

Comparison within Rosalie types:	SED	=	±	8.80
	DF	=		24
Figures are a mean of 18 plants at marketing	LSD (5%)	=	±	18.16
Comparison within and between Arosa and Ilona types:	SED	=	±	4.57
	DF	=		60
Figures are a mean of 36 plants at marketing	LSD (5%)	=	±	9.13

Appendix II

Table 3 **Mean Widest Spread (mm) at marketing**

Cultivar	CO_2 level	Light Level 2500 lux	Light Level 4000 lux
Rosalie types			
Marinella	+ CO_2	274.7	270.6
	- CO_2	287.5	250.8
Anja	+ CO_2	288.3	268.3
	- CO_2	267.8	245.8
Orania	+ CO_2	279.2	270.3
	- CO_2	282.8	247.8
Rosanna	+ CO_2	282.8	298.9
	- CO_2	293.9	250.0
Arosa types			
Karin	+ CO_2	239.6	257.4
	- CO_2	244.9	214.2
Nelson	+ CO_2	232.6	234.0
	- CO_2	228.3	205.8
Ilona types			
Ilona	+ CO_2	258.3	253.2
	- CO_2	255.1	226.1
Netja	+ CO_2	279.7	271.7
	- CO_2	276.1	228.6

Comparison within Rosalie types:	SED	=	±	12.10
	DF	=		24
Figures are a mean of 18 plants at marketing	LSD (5%)	=	±	24.97

Comparison within and between Arosa and Ilona types:	SED	=	±	5.43
	DF	=		60
Figures are a mean of 36 plants at marketing	LSD (5%)	=	±	10.85

Appendix II

Table 4 **Mean Spread 90° to widest point (mm) at marketing**

Cultivar	CO_2 level	Light Level 2500 lux	4000 lux
Rosalie types			
Marinella	+ CO_2	225.3	214.7
	- CO_2	225.6	205.8
Anja	+ CO_2	248.3	225.8
	- CO_2	231.4	203.1
Orania	+ CO_2	226.4	215.0
	- CO_2	234.7	195.0
Rosanna	+ CO_2	236.4	234.2
	- CO_2	231.1	210.6
Arosa types			
Karin	+ CO_2	211.3	212.2
	- CO_2	210.4	180.6
Nelson	+ CO_2	207.3	192.6
	- CO_2	196.3	174.7
Ilona types			
Ilona	+ CO_2	214.2	213.2
	- CO_2	203.9	182.5
Netja	+ CO_2	220.3	215.0
	- CO_2	223.9	195.1

Comparison within Rosalie types:	SED	=	±	10.90
	DF	=		24
Figures are a mean of 18 plants at marketing	LSD (5%)	=	±	22.50
Comparison within and between Arosa and Ilona types:	SED	=	±	5.09
	DF	=		60
Figures are a mean of 36 plants at marketing	LSD (5%)	=	±	10.18

Appendix II

Table 5 **Mean Overall Spread (mm) at marketing**

Cultivar	CO_2 level	Light Level 2500 lux	Light Level 4000 lux
Rosalie types			
Marinella	+ CO_2	250.0	242.6
	- CO_2	256.5	228.3
Anja	+ CO_2	268.3	247.1
	- CO_2	249.6	224.4
Orania	+ CO_2	252.8	242.6
	- CO_2	258.7	221.4
Rosanna	+ CO_2	259.6	266.5
	- CO_2	262.5	230.3
Arosa types			
Karin	+ CO_2	225.4	234.8
	- CO_2	227.6	197.4
Nelson	+ CO_2	220.2	213.3
	- CO_2	212.3	190.3
Ilona types			
Ilona	+ CO_2	236.3	233.2
	- CO_2	229.5	204.3
Netja	+ CO_2	250.0	243.3
	- CO_2	250.0	211.9

Comparison within Rosalie types:	SED	=	±	10.72
	DF	=		24
Figures are a mean of 18 plants at marketing	LSD (5%)	=	±	22.13
Comparison within and between Arosa and Ilona types:	SED	=	±	4.66
	DF	=		60
Figures are a mean of 36 plants at marketing	LSD (5%)	=	±	9.33

Appendix II

Table 6 Mean Number of Flowers > 50% Open at marketing

Cultivar	CO_2 level	Light Level 2500 lux	4000 lux
Rosalie types			
Marinella	+ CO_2	5.61	6.22
	- CO_2	5.28	9.33
Anja	+ CO_2	7.22	5.22
	- CO_2	5.33	6.89
Orania	+ CO_2	7.78	6.00
	- CO_2	5.39	8.89
Rosanna	+ CO_2	5.94	6.06
	- CO_2	6.28	9.89
Arosa types			
Karin	+ CO_2	8.36	10.33
	- CO_2	7.25	9.44
Nelson	+ CO_2	7.53	7.78
	- CO_2	6.69	9.58
Ilona types			
Ilona	+ CO_2	5.94	5.44
	- CO_2	4.86	5.83
Netja	+ CO_2	5.42	3.39
	- CO_2	5.69	3.83

Comparison within Rosalie types:	SED	=	±	1.028
	DF	=		24
Figures are a mean of 18 plants at marketing	LSD (5%)	=	±	2.122
Comparison within and between Arosa and Ilona types:	SED	=	±	0.66
	DF	=		60
Figures are a mean of 36 plants at marketing	LSD (5%)	=	±	1.328

Appendix II

Table 7 **Mean Number of Coloured Buds at marketing**

Cultivar	CO_2 level	Light Level 2500 lux	4000 lux
Rosalie types			
Marinella	+ CO_2	20.67	24.72
	- CO_2	19.78	27.44
Anja	+ CO_2	22.33	18.72
	- CO_2	18.28	22.67
Orania	+ CO_2	19.33	20.67
	- CO_2	20.44	28.33
Rosanna	+ CO_2	21.83	22.67
	- CO_2	21.11	28.44
Arosa types			
Karin	+ CO_2	15.42	14.56
	- CO_2	12.89	14.25
Nelson	+ CO_2	20.25	19.75
	- CO_2	19.03	20.44
Ilona types			
Ilona	+ CO_2	20.92	23.31
	- CO_2	18.81	18.64
Netja	+ CO_2	17.42	16.44
	- CO_2	20.19	17.72

Comparison within Rosalie types:	SED	=	±	2.381
	DF	=		24
Figures are a mean of 18 plants at marketing	LSD (5%)	=	±	4.914
Comparison within and between Arosa and Ilona types:	SED	=	±	1.249
	DF	=		60
Figures are a mean of 36 plants at marketing	LSD (5%)	=	±	2.498

Appendix II

Table 8 **Mean Quality Score at marketing (3 being best)**

Cultivar	CO_2 level	Light Level 2500 lux	4000 lux
Rosalie types			
Marinella	+ CO_2	1.611	2.056
	- CO_2	1.556	1.111
Anja	+ CO_2	1.556	2.278
	- CO_2	1.500	1.611
Orania	+ CO_2	2.333	2.833
	- CO_2	2.278	2.556
Rosanna	+ CO_2	1.889	2.333
	- CO_2	1.500	2.333
Arosa types			
Karin	+ CO_2	1.056	1.000
	- CO_2	1.000	1.500
Nelson	+ CO_2	1.278	1.417
	- CO_2	1.361	2.056
Ilona types			
Ilona	+ CO_2	1.222	1.278
	- CO_2	1.361	2.056
Netja	+ CO_2	1.361	1.333
	- CO_2	1.111	1.861

Comparison within Rosalie types:	SED	=	±	0.2175
	DF	=		24
Figures are a mean of 18 plants at marketing	LSD (5%)	=	±	0.4489
Comparison within and between Arosa and Ilona types:	SED	=	±	0.1050
	DF	=		60
Figures are a mean of 36 plants at marketing	LSD (5%)	=	±	0.2100

Appendix III

Quality Scores

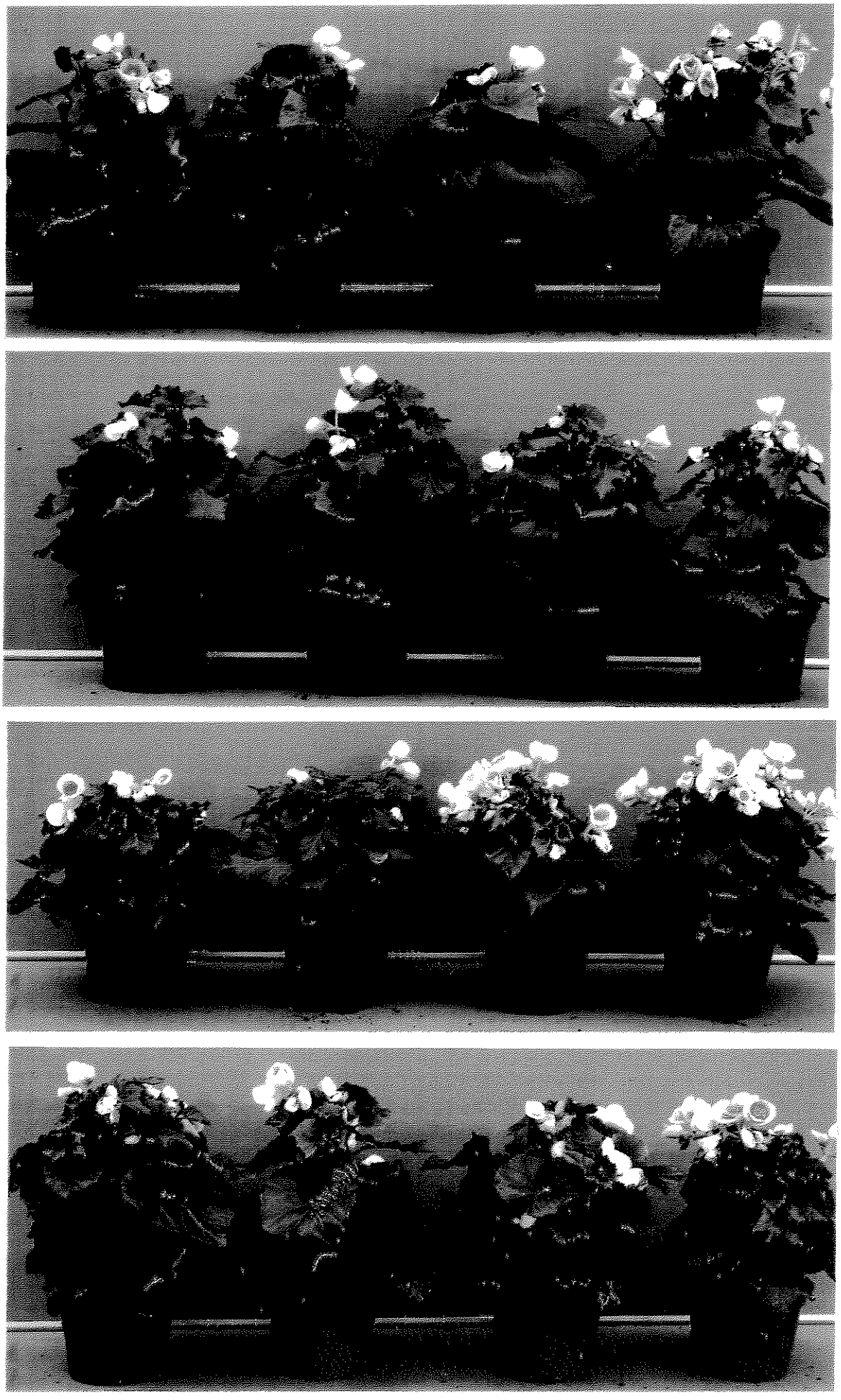
Plate 1 Rosanna

Score 3 2 1

Plate 2 Nelson

Score 3 2 1

2500 lux + CO_2 2500 lux 4000 lux + CO_2 4000 lux



2500 lux + CO_2 2500 lux 4000 lux + CO_2 4000 lux