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Project Number:	PC 158
Project Leaders:	Dr Sean Clifford (Production and post-harvest phase; Author) HRI Efford, Lymington, Hampshire, SO41 0LZ Dr Simon Pearson (modeling) Dept Hort and Landscape, University of Reading, Whiteknights, PO Box 221, Reading, RG6 6AS
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Key Workers:	**HRI Efford:** Dr Sean Clifford — Project Leader (author) Mrs Shirley Foster — Scientific Officer Miss Sarah Williams — Assistant Scientific Officer Miss Ann Peek — Nursery Staff Mr Paul Burnell — Nursery Staff Mr Chris Vigor — Nursery Staff (Foreman) **HRI Wellesbourne:** Mr A Mead (MSc) — Biometrics **Reading University:** Dr Simon Pearson **ADAS Guildford:** Mr Tim Briercliffe — Ethylene analysis
Project Co-ordinator:	Mr Michael Townsend, Nielsen Plants Ltd, Hellingly, Sussex.
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1 PRACTICAL SECTION FOR GROWERS

1.1. Background and objectives

New Guinea Impatiens (NGI) are becoming increasingly popular as plants that can be used in the house during the spring, with the potential for planting out into the garden during summer to provide extended flowering on the patio or in the border. In order to be successfully marketed in the pot plant sector, any flowering product needs to be able to maintain high quality open flowers through the marketing phase, with the potential for continued bud development and flowering for the consumer. The main problem facing NGI production and sales is the tendency for high levels of premature bud and flower drop during the marketing chain and post-harvest, which lead to consumer dissatisfaction. Previous work has indicated that the use of supplementary lighting, altered nutrient status at marketing and the application of anti-ethylene agents may all be factors affecting flowering and floral longevity in NGI.

NGI flowers have been shown to be extremely sensitive to ethylene gas, with high levels of flower and bud abscission even after short periods of exposure to low levels of ethylene gas (Dostal *et al*, 1991). Ethylene exposure can take several forms: firstly as an external pollutant from exhaust fumes which is reported as a particularly severe ethylene producer (for review see Langton, 1997), or in mixed transport with ripe fruit and vegetables; and secondly as a naturally occurring product synthesised within the plant itself. Both of these sources of ethylene have been shown to be damaging to NGI flowers (Dostal *et al.*, 1991).

Previous HDC (PC 80) and MAFF-funded (HH1308TPC) projects on NGI have investigated the effects of temperature, nutrition, lighting and commercially available anti-ethylene compounds on flowering and post-harvest flower performance. The HDC work showed that there were large effects of production temperature, with high temperatures reducing production time (nb. high temperatures early on may inhibit flower induction), but also resulting in poorer quality and post-harvest performance. 2.5 klx lighting for 12 hours per day had little benefit in terms of crop duration, but improved uniformity. Overall, the benefits of this treatment were considered to be small.

NGI are not photo-periodic, but do respond to light integral, and treatments which extended the photo-period from 12 to 16 hours increased flower numbers. The MAFF-funded work highlighted the sensitivity of flowering to the combined effects of light level and temperature, with optimal flower production over a narrow temperature range. This range could move according to light level, so that under low light conditions, flowering was better at low temperatures and at high light the opposite was true.

Following on from the MAFF programme of work on scheduling of NGI for the summer season, there was a need to extend this work and apply it to the early-season period. During this time of year, the use of supplementary lighting and elevated CO_2 could provide considerable benefits for NGI production both in terms of product quality and post-harvest performance.

In the above projects, attempts to demonstrate the effectiveness of chemical flower stickers in promoting post-harvest flower longevity were largely inconclusive, as flowers and bud losses were not high in the control treatments. In order to provide a challenge to the applied treatments, the current study investigated the post-harvest performance of buds and flowers in control and treated pots which had been exposed to ethylene at marketing.

Several anti-ethylene agents are currently available. Amino-oxyacetic acid (AOA) inhibits ethylene synthesis in the plant and can provide protection against natural endogenous ethylene, but ***not*** against ethylene when present as a pollutant. Communication with Chrysal who produce 'EVB' an AOA-like compound has revealed that, although this product has benefits when used on *Dianthus* as a cut flower, their research data indicate that it would not be useful for pot plants.

More practical approaches involve the application of products which bind to the ethylene receptor sites in the plant, effectively blocking the ethylene sensitivity of the plant. Commercially, silver thiosulphate (STS), marketed in the UK as Argylene (Fargro Ltd) or AVB-S (Chrysal: not UK registered) can be applied to promote flower and bud longevity. Application of STS has been shown to produce leaf and flower spotting, both of which reduce crop quality and value, and result in increased labour costs associated with "cleaning" the plant (removing damaged flowers / leaves) as it is packed for marketing. There are also increasing environmental concerns over the continued use of STS in the ornamentals industry, and new silver-free products need to be identified and tested. One is 1-methyl-cyclopropane (1-MCP), which has been developed in the US by Floralife, and a commercial product called 'EthylBloc®' is due to be registered in Europe soon. It is a non-toxic compound applied as a gas to the crop at marketing (available as a powder to which water is added). The many benefits in terms of low phytotoxicity, environmental friendliness, user safety and efficacy of 1-MCP- relative to STS-based products have been published in the scientific literature during the last 4 years.

To date, no trials have considered the potential benefits of elevated CO_2 and 3 klx assimilation lighting under extended photo-period, in combination with chemical "flower stickers", to further improve post-harvest flowering and longevity in this crop.

The specific objectives of the work were to:

(i) Identify potential levels of exposure to ethylene during the transport and marketing chains.

(iii) Test the efficacy of 'EthylBloc®' (1-MCP), the new silver-free alternative to STS.

(iv) Test the efficacy of assimilation lighting and elevated CO_2 with and without ethylene inhibitors as cultural techniques for promoting extended post-harvest performance in NGI.

1.2 Summary of results

Details of the trial

The NGI variety Granada (Paradise series supplied by Dümmen), were potted in week 02 for production in 10 cm pots.

Plants were grown at each of 2 light levels:

- Ambient light with natural daylength
- 3 klx (7.5 W/m^2) for 16 hours / day starting at midnight

and at 2 CO_2 concentrations:

- ambient
- 1000 vpm.

Onto each of these cultural treatments were superimposed the following chemical flower sticker treatments:

- Control (no chemicals).
- STS either applied once at 2 g/l a week before marketing, twice at 1 g/l, 12 days and a week before marketing, 0.7 g/l three times, 17, 12 days and a week before marketing. The repeated lower concentrations tested whether the same effect could be achieved using several weak applications, but avoiding the problems of flower and leaf damage associated with application at the full rate.
- EthylBloc® applied either once at marketing, or twice: at bud colour and again at marketing.

At marketing, plants from each treatment were either transferred directly into shelf-life, or exposed to 0.5 - 1 ppm ethylene for 4 hours before starting the post-harvest phase. The effects of production lighting, CO_2 and chemical treatments were assessed post-harvest following ethylene exposure.

Main Results

1. Elevated CO_2 (1000 ppm) and supplementary lighting (3klx or 7.5 W/m^2), lead to a 17 day reduction in crop duration, increased plant bulk (33% increase in plant dry weight), more uniform plant height, and increased bud numbers (primarily driven by CO_2 enrichment). Elevated CO_2 under ambient light reduced cropping by one week and increased plant dry weight by 17%.

2. Production using elevated CO_2 and supplementary lighting reduced variability in time to flowering, compared to ambient conditions, offering the potential for improved scheduling of the early-season crop.

3. From the available data, there were no indications of high levels of ethylene at any point in the marketing chain, but the need for care under certain conditions was highlighted.

4. Application of EthylBloc® at marketing resulted in less flower and leaf damage than using STS, although repeated applications of STS at lower rates leading up to marketing did reduce damage levels. This has implications for reducing labour costs during packing.

5. EthylBloc® resulted in significant reductions in bud losses for the first week after marketing, with some evidence for reduced flower loss, suggesting that this product has potential for ensuring protection against ethylene from nursery to consumer.

6. The use of elevated CO_2 and supplementary light during production had a greater influence on post-harvest performance than any of the anti-ethylene chemicals.

7. During shelf-life, the benefits from production using elevated CO_2 and supplementary lighting translated into more prolific flowering in the retail phase offering greater impact on the shelf, and also enhanced flower numbers for up to 3 weeks post de-sleeving.

8. While the use of supplementary lighting and elevated CO_2 during production did lead to greater flower and bud number per plant at marketing and even up to 2 weeks post de-sleeving, cumulative flower and bud loss was greater than the control 4 weeks after de-sleeving.

9. Manipulation of nutrition and the use of post-harvest feed supplements may improve post-harvest performance in plants grown under lights and with CO_2. Interactions between production and home-life light environments may also be important in the understanding of how to promote post-harvest longevity in these treatments. This needs further work.

10. New Guinea Impatiens was not as sensitive to ethylene exposure as was expected from previously published work, and this highlighted the need for a fuller understanding of which developmental and environmental factors might be most important in relation to the sensitivity of this species to ethylene. For example, transient fluctuations in transport temperature may be a critical factor determining levels of ethylene production / damage.

11. The development of other techniques such as the use of Ethephon to abort premature buds at potting may offer other ways of more effective scheduling together with cultural techniques such as lighting and CO_2-enrichment.

1.3. Action points for growers

The following points could be incorporated on the nursery to offer immediate benefits to the business during early season production.

- Applying CO_2-enrichment even without supplementary lighting should promote increased plant bulk, reduced crop duration and enhanced bud production and offer greater post-harvest flowering potential for NGI.

- In locations with low ambient light levels, the benefits of using elevated CO_2 will be further enhanced by providing supplementary assimilation lighting over the crop.

- If assimilation lighting is available, its use over the early season crop can shorten cropping and reduce variability in time to flowering, with the potential also for reducing PGR use.

- While supplementary lighting and CO_2 enrichment did lead to higher flower and buds numbers per plant even, up until two weeks post de-sleeving; flower and bud loss was greater than the controls thereafter. This may have implications for consumer satisfaction.

- Where plugs arrive initiated at an early stage of development, the use of CO_2-enrichment and assimilation lighting could enable far higher throughput than is currently possible under ambient conditions.

- When converting to using elevated CO_2 and assimilation lighting, the nutrient regime may need modification to ensure that N and K levels do not become depleted towards the end of production.

- Although New Guinea Impatiens were not as sensitive to ethylene as expected, it is possible that higher temperatures at packing on the nursery, or during transport, especially in enclosed spaces, may enhance either the sensitivity of plants to ethylene, ethylene production, or both. Care should be exercised to ensure adequate ventilation and to avoid high temperature conditions.

- EthylBloc® is not currently registered in the UK., but evidence from this work suggests that it provides a non-damaging treatment for protection against the effects of ethylene for up to a week. This should be sufficient to ensure safe passage of plants from the nursery to the consumer. STS is available in the UK., and data indicate that repeated low-dose applications may cause less damage than the normal single application. The work highlighted the need for application of STS only under low light conditions if damage was to be avoided. It must be emphasised however, that the data from the current trial did not provide conclusive evidence for the benefits of STS as an anti-ethylene treatment, and this was due to the apparent insensitivity of New Guinea Impatiens to the levels of ethylene applied, rather than any shortcomings of STS.

1.4 Practical and anticipated financial benefits

New Guinea Impatiens is a relatively 'new' pot plant crop, with an estimated farm gate value in excess of £2 million, and increasing annually. Quantification of the financial benefits will vary from grower-to-grower, and will largely depend on the availability of assimilation lighting and CO_2.

Production of high quality early-season New Guinea Impatiens with good post-harvest characteristics (before being used in the garden) will ensure continued growth in the market for this crop. Increased throughput due to the use of assimilation lighting may also benefit growers as long as the market can sustain the increase in production. Tighter crop schedules though the use of CO_2-enrichment and supplementary lighting will facilitate more cost-effective use of space in the production environment.

Repeated low doses of STS, (but with the recommended dose being applied cumulatively), may reduce the need for "plant dressing" at packing, thereby saving costly labour time during packing. EthylBloc® looks promising as a non damaging treatment against effects of ethylene during transport, if and when it is registered for use in the UK. If registered beforehand across the rest of Europe it could possibly improve quality of imported ethylene sensitive species, thus increasing competition in the home market.

2 SCIENCE SECTION

2.1 Introduction

New Guinea Impatiens (NGI) are becoming increasingly popular as plants that can be used in the house during the spring, with the potential for planting out into the garden during summer to provide extended flowering on the patio or in the border. In order to be successfully marketed in the pot plant sector, any flowering product needs to be able to maintain high quality open flowers through the marketing phase, with the potential for continued bud development and flowering for the consumer.

NGI flowers have been shown to be extremely sensitive to ethylene gas, with high levels of flower and bud abscission even after short periods of exposure to low levels of ethylene gas (Dostal *et al*, 1991). Ethylene exposure can take several forms: firstly as an external pollutant from exhaust fumes which is reported as a particularly severe ethylene producer (for review see Langton, 1997), or in mixed transport with ripe fruit and vegetables; and secondly as a naturally occurring product synthesised within the plant itself. Both of these sources of ethylene have been shown to be damaging to NGI flowers (Dostal *et al.*, 1991).

There is a large body of research on the effects of ethylene on fruits and flowers. Originally, ethylene was believed to be a plant growth regulator only. However, new analytical techniques have demonstrated that ethylene is produced in plant tissues at very low concentrations, and has been shown to be an important plant hormone involved in many developmental processes including fruit ripening, abscission, senescence, growth, flowering and sex expression (Reid, 1989; Abeles *et al.*, 1992). In conjunction with the synthesis of ethylene in a plant organ, it has also been shown that there is an enhanced sensitivity to ethylene with age, making the response even stronger than it would otherwise have been (Whitehead *et al.*, 1984). In some species, the flowers may only be sensitive to ethylene at particular developmental stages e.g. on the day of anthesis as in *Tradscantia* (Suttle & Kende., 1978). The biochemical pathway for ethylene synthesis has been characterised (see review by Langton, 1997) and synthesis of the ethylene precursor ACC (1-amino cyclopropane- 1-carboxylic acid) can be blocked by the application of AOA (aminooxyacetic acid). However, since endogenously produced ethylene levels generally represent only a small fraction of the concentration that plants may be exposed to from exogenous sources such as ripening fruit or exhaust fumes, AOA is of only limited practical value. Far more practical are chemicals that can inhibit the exogenous ethylene pollutant by binding to the active ethylene receptors on the plant membranes, thereby making them insensitive to the effects of the gas. Several metal compounds have been tested, but by far the most effective to-date has been silver, initially as $AgNO_3$ (Beyer, 1976), and more recently as STS (silver thiosulphate; Veen & Van de Geijn, 1978), which provided the route for low concentration applications of silver with high mobility in the plant tissue. Currently, there is strong environmental pressure to reduce the use of heavy metals which accumulate in the food chain, and the use of STS is becoming restricted.

Of the anti-ethylene agents which are currently available, amino-oxyacetic acid (AOA) inhibits ethylene synthesis in the plant and can provide protection against natural endogenous ethylene, but ***not*** against ethylene when present as a pollutant. Communication with Chrysal who produce 'EVB' an AOA-like compound has revealed that, although this product has benefits when used on *Dianthus* as a cut flower, their research data indicate that it would not be useful for pot plants. Commercially, silver thiosulphate (STS), marketed in the UK as Argylene (Fargro Ltd) or AVB-S (Chrysal: not UK registered) can be applied to promote flower and bud longevity. Application of STS has been shown to produce leaf and flower spotting, both of which reduce crop quality and value, and result in increased labour costs associated with "cleaning" the plant (removing damaged flowers / leaves) as it is packed for marketing. There are also increasing environmental concerns over the continued use of STS in the ornamentals industry, and new silver-free products need to be identified and tested. One is 1-methyl-cyclopropane (1-MCP), which has been developed in the US by Floralife, and a commercial product called 'EthylBloc®' is due to be registered in Europe soon. It is a non-toxic compound applied as a gas to the crop at marketing (available as a powder to which water is added). The many benefits in terms of low phytotoxicity, environmental friendliness, user safety and efficacy of 1-MCP- relative to STS-based products have been published in the scientific literature during the last 4 years (Serek *et al*, 1994; Serak *et al*, 1995 a,b,c,d; Dupille *et al*, 1995; Cross, 1996; Muller *et al*, 1997; Reid *et al*, 1999).

Previous HDC (PC 80) and MAFF-funded (HH1308TPC) projects on NGI have investigated the effects of temperature, nutrition, lighting and commercially available anti-ethylene compounds on flowering and post-harvest flower performance. The HDC work showed that there were large effects of production temperature, with high temperatures reducing production time (nb. high temperatures early on may inhibit flower induction), but also resulting in poorer quality and post-harvest performance. 2.5 klx lighting for 12 hours per day had little benefit in terms of crop duration, but improved uniformity, though overall, the benefits of this treatment were considered to be small.

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In the above projects, attempts to demonstrate the effectiveness of chemical flower stickers in promoting post-harvest flower longevity were largely inconclusive as flowers and bud losses were not high in the control treatments. In order to provide a challenge to the applied treatments, the current study investigated the post-harvest performance of buds and flowers in control and treated pots which had been exposed to ethylene at marketing.

Following on from the MAFF programme of work on scheduling of New Guinea Impatiens for the summer season, there is a need to extend work and apply it to the early-season period. During this time of year, the use of supplementary lighting and elevated CO_2 could provide considerable benefits for NGI production both in terms of product quality and post-harvest performance.

The main problem facing NGI production and sales is the tendency for high levels of premature bud and flower drop during the marketing chain and post-harvest which lead to consumer dissatisfaction. Previous work has indicated that the use of supplementary lighting, altered nutrient status at marketing and the application of anti-ethylene agents may all be factors affecting flowering and floral longevity in NGI. To date, no trials have demonstrated the potential benefits of elevated CO_2 and 3 klx assimilation lighting under extended photo-period in combination with chemical "flower stickers" to further improve post-harvest flowering and longevity in this crop.

2.2. Objectives

The specific objectives of the work were to:

(i) Identify potential levels of exposure to ethylene during the transport and marketing chains.

(ii) Test new protocols to improve application of anti-ethylene chemicals in order to extend effective home-life, maintain harvest quality (in terms of leaf / flower spotting), and reduce the requirements for cleaning plants at packing.

(iii) Test the efficacy of 'EthylBloc®' (1-MCP), the new silver-free alternative to STS.

(iv) Test the efficacy of assimilation lighting and elevated CO_2, with and without ethylene inhibitors, as cultural techniques for improving post-harvest performance in NGI.

2.3. Materials and Methods

2.3.1. Glasshouse site

The trials were conducted in Q Block, compartments 1 & 2 inclusive on the western side. Q Block is a multi-compartment glasshouse with 4 compartments running north – south and each measuring approximately 30 m long by 10 m wide. Within each compartment, there are 3 rows of 4 rolling benches aligned north – south, each bench measuring 7 m by 1.8 m. Irrigation is by hand via capillary matting.

Post-harvest studies were carried out in the Old Conference Room shelf-life facility at HRI Efford.

2.3.2. Trial description

*2.3.2.1 **Plant material***: In week 2, rooted cuttings of New Guinea Impatiens variety "Grenada" (Paradise series) were supplied in plug trays from Dümmen via Hollyacre Plants Ltd.

2.3.2.2 Cultural techniques

Propagation:. Under standard commercial conditions at Hollyacre Plants Ltd (Littlehampton, W. Sussex, UK).

Potting: Plugs were potted into 10 cm pots using Sinclair "Pot Plant" compost.

Spacing: Plants were started pot thick (100 m^{-2}) and with a final spacing of 35 m^{-2} (16.9 cm inter-pot & 11.9 cm inter-row). In the high light and high CO_2 combination, the plants were more bulky, and were spaced to 30 m^{-2} if necessary, to avoid reducing quality due to limitations in spacing rather than applied treatment. When additional spacing was required, this was recorded for consideration in the economics of the crop in the final analysis.

Light: 2 applied lighting treatments (see treatments section 2.3.3 below): ambient and 3 klx supplementary, with supplementary lighting applied for 16 hours/day starting at midnight and finishing at 4 pm (to avoid the highest tariffs).

Temperature: 18°C day / 20°C night (heating / venting set points), with venting set to 22°C when light levels were greater than 400 W/m^2 to take advantage of CO_2 on bright days.

CO_2: 2 levels as per the treatments section: ambient (350 ppm) and elevated (1000 ppm). Set point of 1000 ppm was only applied up to 5% vent position: > 5% set point = 350 ppm

Irrigation: Plants were grown on the dry side.

Nutrition: Liquid feed with 2 : 1 : 2 feed. Stock feed 160 mg/l N : 53 mg/l P : 130 mg/l K. Liquid fed was applied at each watering at a conductivity of 1.5 mS and pH adjusted to pH 6.0. Care was taken to avoid the media conductivity increasing above 2 mS as this has been reported as resulting in reduced plant vigour and delayed flowering.

Pest and Disease Control: Routine scouting was used to support an IPM programme. Biological control agents were introduced at potting and at appropriate intervals against thrips (*Frankinella occidentalis* was combated using *Amblyseius cucurmeris*) and aphid (*Aphidoletes aphidimyza* were introduced). Blue and yellow sticky traps were positioned throughout the crop to monitor insect numbers.

Plant Growth Regulation: Adequate spacing as soon as the leaves touched, together with careful irrigation management meant that no chemical plant growth regulation was necessary.

2.3.3 Treatments

2.3.3.1 Growing phase treatments:

1 variety
x
2 CO_2 concentrations: 350 and 1000 ppm
x
2 light levels : Ambient and 3 klx (7.5 Wm^{-2}; 16 h/d starting at midnight)*

= 4 growing environment treatments

Assimilation lighting provided from high pressure sodium SON-T 400W lamps.

The application of 3 klx assimilation lighting for 16 hours per day equates to approximately 2.16 $mol/m^2/day$ (3 klx = 7.5 W/m^2 = 37.5 $\mu mol/m^2/sec$) in addition to ambient incident light in the glasshouse.

Assimilation lights were applied in the northern half of the compartment, and a low-level screen was drawn at night to avoid light spill. This system ensured that ambient light levels were not compromised in any of the plots during the day.

2.3.3.2 Treatments applied towards the end of production / at marketing.

2 replicate plots of each of the following treatments:

Control (no STS or EthylBloc® treatment)

Three STS treatments:

(i) applied at 2 g/l 7 days prior to marketing
(ii) applied twice at 1 g/l, 12 and 7 days prior to marketing
(iii) applied three times at 0.7 g/l, 17, 12 and 7 days prior to marketing

Two 1-MCP (EthylBloc®) treatments:

(i) Applied at 180 mg/m^3 (300 ppb) at marketing
(ii) Applied at 180 mg/m^3 (300 ppb) at bud colour and again at marketing*

* Literature accompanying the ElthylBloc® product reported that there were no detrimental effects of repeated exposure to EthylBloc® and that this may in fact be beneficial. It was stated, however, that material which had already been treated with STS ***should not*** subsequently be treated with EthylBloc®. This was not for safety reasons, but due to the fact that EthlyBloc® would not work in this situation (ethylene receptors already filled).

Controlled exposure of plants to EthylBloc® was achieved in a sealed, purpose-built polythene chamber. For description and standard operating procedure, see section 2.3.4 below.

Total of 6 market stage treatments

2.3.3.3 Treatments applied immediately prior to shelf-life:

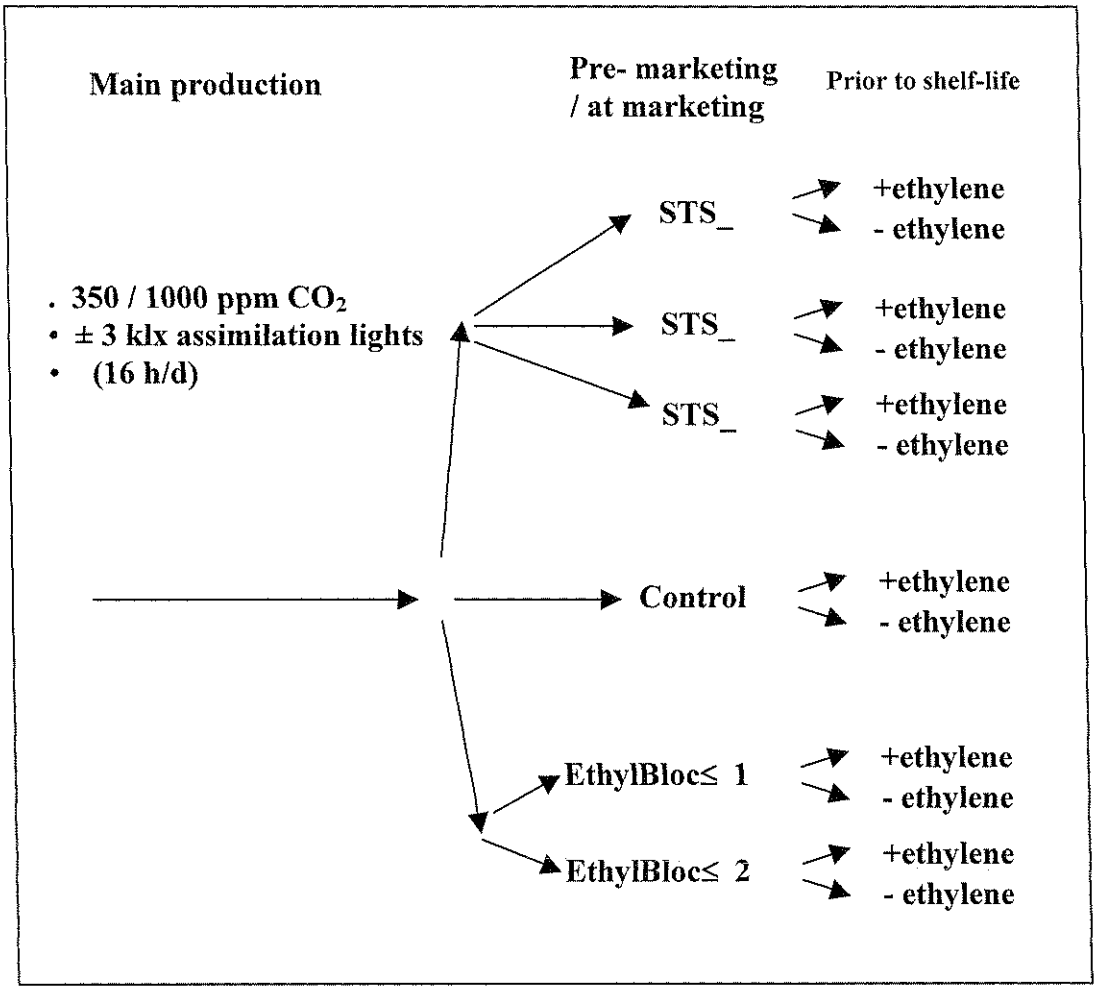
At marketing, pots were removed from the bench, and 4 representative pots from each replicate plot were exposed to ethylene gas generated by a BRM 9002 ethylene generator for 4 hours. The target ethylene concentration was 1 ppm, based on the report by Dostal *et al* (1991), in which they suggested that NGI lost 80% of their flowers after a 4 hour exposure to 1 ppm ethylene.

This gave a total of :

4 growing treatments x 6 chemical treatments x 2 ethylene treatments x 2 reps
= 96 plots into shelf-life

A flow diagram showing the sequence of treatments is presented in Figure 1 and treatment layouts for the production phase can be seen in Appendix 1.

Figure 1: Flow diagram of the sequence of treatments.



In order to determine the levels of ethylene to which plants were exposed to during the trial, samples were collected according to the method described in section 2.3.6 using Tedlar bags. This technique was preferred to the use of Gastec tubes which are relatively crude and imprecise at the ethylene levels applied in the current trial.

2.3.4 Ethylbloc® exposure

The following operating procedure describes the optimal operation of the experimental EthylBloc exposure chamber (0.248 m^3). Potted plants (24 max) were treated with the gaseous anti-ethylene compound EthylBloc (1-methylcyclopropene) at the recommended rate of 300 ppb. Exposure was always carried out at night for 15 – 16 hours (from 5 pm to 8:30 am)

Figure 2 shows the components of the chamber. It comprised a plastic housing, the base of which was immersed in a trough containing water. A twin sheet of heavy gauge polythene lined the base of the chamber and ran out through the water-filled trough, thereby making a gas-tight seal. The integrity of the polythene sheet was checked prior to each exposure.

The chamber housing had four ports, each sealed for gas-tightness. On top: the mixing chamber access port through which the buffer for dissolving the EthylBloc was added. The two ports at the top on the side were opened as air inlets when exhausting the chamber after exposure had finished. On the opposite side of the chamber was the exhaust port. This was sealed with a valve which could be opened to draw the chamber air out to vent it after treatment was complete. This valve was closed during treatment. An electric fan inside the chamber ensured uniform distribution of the EthylBloc® gas during treatment.

Before operation, 43 – 47 mg of EthylBloc was accurately weighed using a 4 decimal place chemical balance. The mixing chamber was unscrewed from the main housing and taken to the laboratory. The EthylBloc was put into the mixing chamber in the laboratory before being transported back to the glasshouse (in a suitable container to prevent any loss of material during transit).

The following steps were conducted for each exposure operation:

1) Plastic base sheet was checked for damage.

2) Water trough was filled to 2 cm from the top with water.

3) Pot plants were arranged on base, ensuring that the side branches would not be damaged by the chamber sides when the top was in position.

4) The mixing chamber containing the pre-weighed EthylBloc was screwed into position from under the housing.

5) The exhaust port valves were ALL OPENED (to allow pressure equilibration when the housing was being positioned).

6) The housing was carefully positioned over the plants ensuring they were not damaged and that the housing rim was completely immersed in the water trough. The housing was lowered very slowly to allow pressure escape through the exhaust valve pipes.

7) Once the housing was in place the inlets and exhaust valves were closed.

8) The mixing chamber cap was unscrewed, and using a long bulb pipette, 1.0 ml of 0.9% KOH, (potassium hydroxide), was carefully and quickly added to the powder.

9) The pipette was quickly withdrawn, and a rod inserted to mix the reaction solution for 5 seconds before replacing the lid.

10) The internal fan was switched on.

To avoid high temperatures in the chamber, the corridor was screened and the chamber housing covered with reflective aluminium cloth.

Venting

11) After the exposure period had elapsed, the chamber was carefully vented to the outside.

12) The fan was unplugged and a vacuum hose attached to the exhaust port, with the vacuum cleaner outside the glasshouse (in a dry position).

13) The exhaust valves were opened.

14) The vent caps were opened and the vacuum cleaner switched on. It was important not to turn the vacuum on before opening the ports as the water level inside the chamber would rise very quickly and could spoil the plants.

15) The chamber was left to exhaust for 5 minutes to ensure thorough venting.

16) After the chamber had been fully vented, the buffer remaining in the mixing chamber was carefully removed using a bulb pipette before lifting the housing off.

17) All ports were opened and the chamber housing was lifted off the plants taking care to avoid dripping water onto the foliage. Plants were allowed to stand for an hour to dry off any water droplets that might have formed on the leaves in the high humidity, before being taken for ethylene exposure or into shelf-life.

In relation to the use of EthylBloc® it must be noted at this stage that commercially, the application would either have to be applied at the nursery, or in the trailer of the transport lorry. If the transport were not sealed, the EthylBloc® treatment would be ineffective, and its efficacy would also be reduced if temperatures in the lorry were low. Development of procedures for exposure at the commercial scale need to be considered, but are beyond the scope of the current trial.

2.3.5 Ethylene exposure

At marketing, 4 pots from each treatment were taken directly into shelf-life, with another 4 subjected to ethylene exposure. Ethylene exposure was carried out in Shelf-life Room 3 in the new packing shed. The original proposal suggested the use of Ethrel C (Hortichem Ltd) to simulate ethylene exposure. Ethrel C acts by stimulating endogenous ethylene synthesis in the treated plants. Some research has used this technique (de Stigter, 1980; Van Staden, 1988), and although it does have some practical attractions, it is not recommended for this purpose, since there is a danger of eliciting physiological responses other than those which would normally result from ethylene pollution at meaningful levels (Reid *et al.,* 1980).

For this reason, plants were exposed to exogenous ethylene produced by an ethylene generator (BRM Agencies Model 9002). The following technique was used to generate ethylene concentrations in the range 0.6 – 1 ppm over a 4 hour period. On several occasions, measurements were taken to check exposure levels during the 4 hour period, and the initial levels were maintained throughout the period of exposure.

When the ethylene gas generator was at operating temperature, a pump operated to release ethylene gas into the environment through an outlet on top of the unit.

The generator used ***only*** the proprietary "ripening fluid" supplied by BRM. The fluid was highly flammable and was securely stored away from sources of ignition in a locked flammables store according to COSHH regulations.

Aim: To generate a 1 ppm ethylene concentration in Shelf-life Room 3 in the new packing shed for exposure of New Guinea Impatiens to an ethylene challenge immediately post-marketing.

Operation

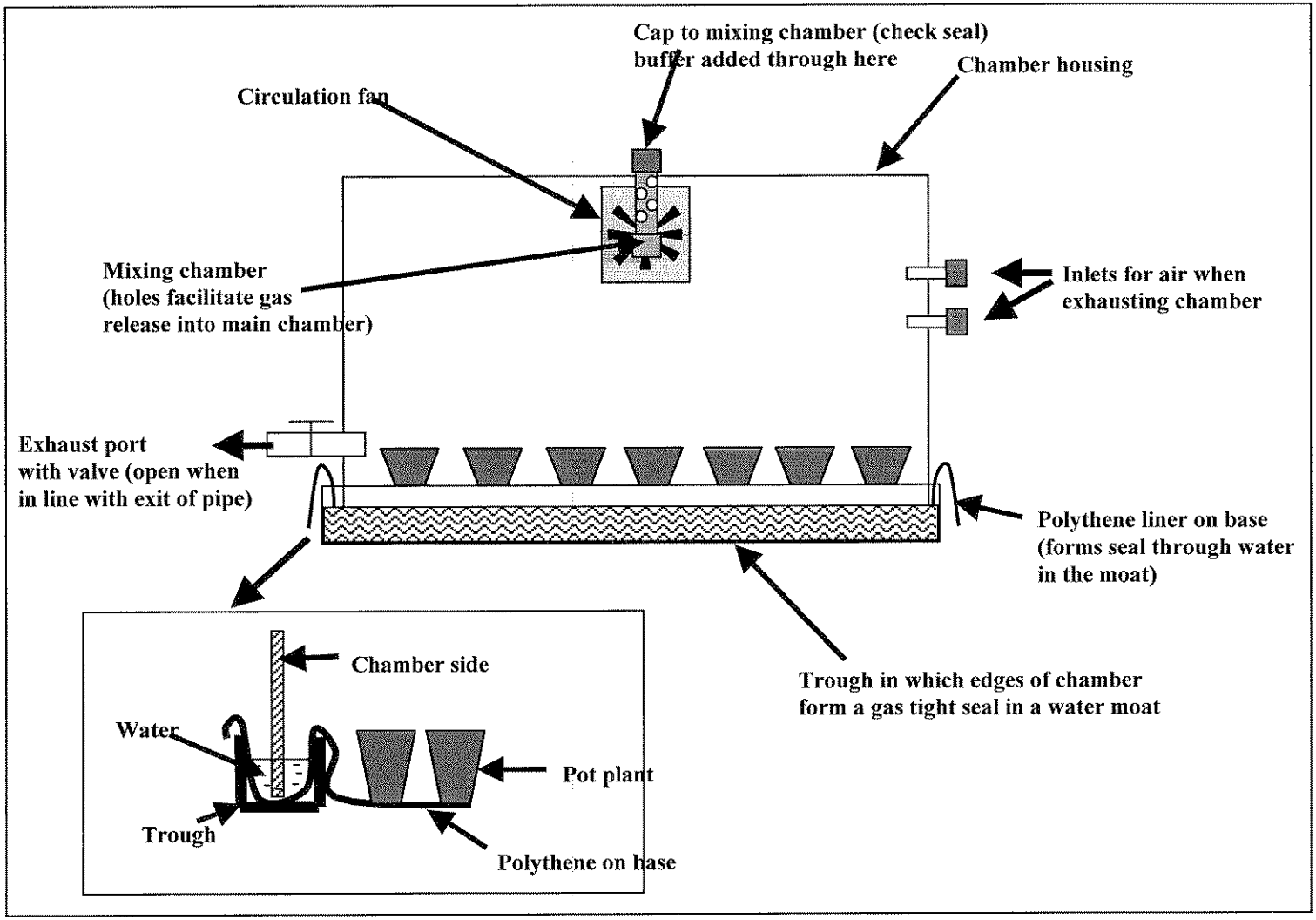
1) Shelf-life environment set to 18-20°C, with RH approx. 60 – 70%.

2) Vehicle access doors at each end of the packing shed were opened 2-3 feet each to allow a free flow of air through the shed.

3) The ethylene generator was placed close to shelf-life room, and in a down wind position.

4) The steel lid was unscrewed and "ripening fluid" was dispensed into the reservoir to cover the shelf. About ¼ litre was generally sufficient. The lid was secured.

Figure 2: Diagram of the EthylBloc® exposure chamber



5) The generator was switched on and allowed it to warm up fully. This took about 5-10 minutes.

6) Occasionally, the red OVERHEAT lights illuminated. This was not a problem, and when it occurred, the unit was left switched on until it re-stabilised.

7) Once the unit was at operating temperature it clicked every 12 – 13 seconds as the pump valve opened to produce a burst of ethylene from the brass opening on the top of the unit.

8) A 250 ml conical flask was positioned over the outlet and filled with ethylene gas before being sealed with a piece of Parafilm.

9) The flask was quickly transferred into the shelf-life room and the door closed.

10) The flask was positioned in the furthest corner from the door in an upright position and above the bench top.

11) The Parafilm was removed and the operator quickly exited the room ensuring that the door was opened as little and for as short a time as possible.

12) Plants were left in the room for 4 hours before being removed to the shelf-life environment.

2.3.6 Ethylene sampling and analysis techniques

One of the objectives of the study was to collect samples of air at strategic points throughout the transport and marketing chain from the nursery into the store, in order to identify the typical range of ethylene concentrations during a marketing run. To achieve this, access to the Sainsbury marketing chain was arranged from Double H Nurseries in Hampshire, travelling through the Swindon depot and finishing at Sainsbury's in Reading.

Air samples were taken as required according the following procedures:

Sampling: Air to be analysed for ethylene concentrations was collected in 2 litre Tedlar Air and Gas Sampling Bags (Supelco cat no. 2-4654). Air was drawn into the bags, which were sealed with a polypropylene 2-in-1 valve, by use of a Casella SP 15 Sampling Pump. The air was drawn into the bag at approximately 200 ml/min and the bag took c. 10 minutes to fill. Where possible, during the 10 minute collection period, the pump inlet was moved across the area from which air was to be collected to ensure good coverage of the sampled environment. In cases where this was

not possible (in sealed boxes or shelf-life rooms), the inlet was supported in the centre of the environment in an exposed position.

Following sampling the bags were labelled and transported, as soon as possible, to the School of Plant Sciences at the University of Reading. All samples were analysed within 24 hours of sampling.

Analysis: 1 ml air samples were removed from the sampling bags using a plastic syringe. The ethylene concentration in the extracted samples was measured by gas chromatography. A Pye series 104 chromatograph was used with N_2 as the carrier gas at a flow rate of 40 ml/min at 60°C. A 1 m long Porapak column with an internal diameter of 2 mm was used. Under these conditions the retention time of ethylene was approximately 120 seconds. Peak heights (PH) of ethylene were recorded and the concentration was determined by reference to a standard of known concentration (10.1 ppm, v/v). Depending on the ethylene concentration the peak height was scaled by attenuation (Att), this is allowed for when calculating ethylene concentration as follows:

$$\text{Head space ethylene concentration (nl/ml)} = \frac{PH_{sample} \times Att_{sample} \times 10.1}{PH_{standard} \times Att_{standard}}$$

Three samples were taken from each bag and the mean was calculated. Ethylene concentration in nl/ml is equivalent to ppm (parts per million) in air. New standard peak heights were recorded at each new analysis session.

Samples were collected in the following environments:

a) Samples from the Efford production environment

In the growing area in Q block
During the boxed phase.
In the shelf life environment.

b) Commercial production and multiple retail transport chain

(i) ***On the nursery:***

In the production area
In the packing area
In the box immediately prior to dispatch
In the loading bay (± lorry engine running)

(ii) ***At the distribution warehouse in the multiple retail):***

In the container of the lorry immediately prior to unpacking

In the box

(ii) ***In the retail outlet:***

In the box immediately prior to unpacking in the store

In the sleeve at the retail display point in the supermarket

Additional samples were taken to monitor ethylene exposure levels in Shelf-life Room 3 during the trial. There were also small-scale trials further investigating the efficacy of EthylBloc® for which data are available, and which will be discussed.

2.3.7 Experimental records

2.3.7.1 Production records

At potting:

To ascertain the degree of variability in time to flowering due to stock plant management, 50 plants were dissected to assess the degree of main-stem flower initiation. The 14 point flowering stage protocol developed at HRI-W during controlled environment MAFF funded work was used to describe bud stages.

Flowering pre-marketing (30 pots/plot):

Time to first flower
If first flower was premature, then time to first flower of second flush (main flowering)
Time to marketing (4 open flowers).

At marketing : 4 open flowers and plant spread covering pot (12 pots / replicate plot):

Plant height (from bench to top of plant) - cm
Plant spread - cm
Number of branches
Number of open flowers
Number of buds (coloured and green)
Flower diameter -
Number of damaged flowers (damaged by anti-ethylene treatment); plus photographic records of types of damage observed.
Leaf damage score (0-3: 0 = none; 1 – slight; 2 = moderate; 3 = severe (where severe = > 50% leaves affected))
Above ground dry weight (pot-by-pot for 5 pots / plot) - g

At marketing, pots were treated as required with EthylBloc® and ethylene before being transferred into shelf-life. In shelf-life, pots were sleeved for 7 days (2 days boxed) before being de-sleeved and maintained in shelf-life for a further 4 weeks.

2.3.7.2 Shelf-life records (4 pots / replicate treatment):

The pots taken into shelf-life were a subset of those recorded at marketing, so that variability at marketing could be tracked though shelf-life.

The following records were taken at de-sleeving and weekly for 4 weeks:

Number of open flowers
Number of dropped flowers
Number of buds (coloured / green: at start and end of shelf-life ONLY)
Number of dropped buds (coloured / green)
Number of damaged flowers (treatment-damaged)
Leaf drop
Flower diameter (at end of shelf-life only to compare with that at marketing)
Flower colour (@ start and end of shelf-life only).

Media analysis:

Compost samples were analysed at potting & every 3 weeks to determine effects of CO_2 / lighting treatments.
Liquid feed analysis
Foliar analysis at marketing to determine effects of CO_2 / lighting treatments (bulked sample from control plots within each light x CO_2 area)

2.3.7.3 Environmental records

Production phase:

External light (weekly average in $MJ/m^2/day$)
External day and night temperatures (°C)
Light levels in ambient treatments (Kipp solarimeters)
Compartment temperature (°C; D / N / 24h average)
Compartment RH (%; D / N / 24h average)
Compartment CO_2 concentration (ppm)

Post-harvest phase, weekly averages for:

Temperature (°C)
Humidity (% RH)

2.3.8. Statistical analysis

***Design*:** Two CO_2 treatments (350 and 1000 ppm, applied to whole compartments) and two light levels (Ambient and Ambient + 3 klx, applied to half compartments) were set up, with two replicates arranged east and west within each lighting x CO_2 regime. Pots were randomly assigned to the different environmental treatments and considered as four main plots within each of two replicates.

Within each CO_2 / light / replicate area there were six marketing stage treatments (untreated control, 3 STS treatments and 2 EthylBloc® treatments).

Just prior to the start of shelf-life, pots from each plot were either exposed to ethylene or not (sub-plot treatment).

Analysis: All variates were analysed using analysis of variance (ANOVA) using Genstat version 5.41.

Statistical terms used include:

L.S.D.	Least significant difference
P = 0.05 or 5%	The probability of this result occurring purely by chance is equal to 1 in 20

2.3.9. Additional test: extent of the effects of EthylBloc®

In addition to the main trial, a study was conducted to assess the longevity of the effects of EthylBloc® post-harvest. On the 1/7/99, plants of the variety Orange Star (ex Dümmen, grown at HRI Efford under standard commercial conditions) were taken into shelf-life after having been exposed to the following treatments:

1) Control (sleeved and boxed)
2) Treated with EthylBloc® as described in section 2.3.4.
3) Given 4 hours exposure to 3 ppm ethylene as previously described in section 2.3.5.
4) Exposed to ethylene AFTER having been treated with EthylBloc®

Plants were kept in sealed boxes for 2 days, before being stood out in the post-harvest environment (600 lux for 14 hours/day at 20°C and 60 –70% RH)

Numbers of open flowers, buds and bud and flower losses were recorded at sleeving, de-sleeving (6 days later), and 9 and 14 days after sleeving.

2.4 RESULTS AND DISCUSSION

2.4.1 Environmental data (graphs in Appendix 3)

The trial was conducted against the background of external ambient temperature and light as presented in Appendix 3, Figs. 1a & b (respectively). External temperatures varied between about 6 and 12°C, with night dips to 2°C and 3.5°C in weeks 6 and 15 respectively. Light levels started at 2.5 MJ/m^2/day in week 2 and increased gradually to about 8 MJ/m^2/day by week 10. There was a rapid increase in ambient light level during week 11, which coincided with an increase in ventilation rates and a corresponding decrease in the CO_2 level that could be maintained in the elevated CO_2 treatment (Appendix 3, Figs. 3a & b).

Compartment temperatures ran in line, with the average 24 hour temperature close to 19°C, and the day temperature ranging from 19°C in week 2 to 22°C as light levels increased after week 10 (Appendix 3, Fig. 2a). Relative humidity was always in the range 55 –80%, with an average of 65-68% (Appendix 3, Fig. 2b).

The elevated CO_2 compartment maintained daytime CO_2 concentrations of 800 – 1000 ppm between weeks 2 and 10 (Appendix 3, Fig. 3a). Thereafter increased ventilation reduced average CO_2 levels to about 650 ppm, but with some variability depending on day-to-day weather conditions. In the ambient CO_2 treatment, daytime CO_2 concentrations started at 400 ppm, but as the canopy developed there was a gradual depletion in average daytime CO_2 level, so that by weeks 12–13 CO_2 was seen to dip as low as 300 ppm during high irradiance days (Appendix 3, Fig. 3b). This highlights the importance of maintaining CO_2 levels within the glasshouse to avoid daytime depletion, even early in the year. Data that is presented for plant growth later in section 2.4.3 demonstrates the significance of using elevated CO_2 even under ambient light conditions for improved early-season production of New Guinea Impatiens.

2.4.2 Stage of flower initiation in plugs at potting.

In order to be able to allow for the effects of any premature flower bud initiation on the Reading flowering model, 100 plugs were randomly sampled and assessed for the presence of reproductive structures. This was done according to the 14 point flowering scale developed by Dr Allen Langton during the MAFF research on modelling effects of environment on development in NGI. There was no evidence of any premature reproductive development in the material used for the trial. It was interesting to note that other varieties which had been sourced from the same supplier had advanced bud development in the plug tray. Further investigation revealed that the batches of plants had been produced under different conditions of temperature, light and photoperiod (Germany and Costa Rica), and this would have affected development at that stage. The area of how plug plant manipulation can affect the resultant crop schedule needs further work.

2.4.3 Marketing data (Graphs in Appendix 4)

Crop duration, plant size and flower and bud numbers were all affected primarily by environmental regime, i.e. the use of assimilation lighting and CO_2 during production, with no significant effects of applied chemical treatments. For this reason, data for the above recorded variables have been presented in terms of the main effects of light and CO_2.

2.4.3.1 *Effects of supplementary lighting and elevated CO_2 on crop duration:*

Both increasing the light level (and duration) by using assimilation lights, and providing elevated CO_2, resulted in significant reductions in crop duration (Table 1; Appendix 4, Fig. 1a). The greatest savings in crop duration were observed in response to supplementary lighting (approximately 12¼ days). The combination of lighting and elevated CO_2 provided small additional reductions in duration (2 days). The extra inputs in providing both treatments would need to be weighed up in relation to the increases in plant bulk, (see next section), and uniformity. Although the reduction in crop duration was smaller using CO_2 alone, the cost of applying this treatment would be less than that of installing and running assimilation lights, and may be attractive in the short-term to promote increased early-season productivity in the absence of assimilation lights over the production area.

Previous HDC-funded research in PC 80a showed that increasing temperature by 10°C, from 15 to 25°C, reduced crop duration in early season NGI crops, but that there were relatively small effects of additional light. It was also demonstrated that stem length was increased with temperature. If temperature had been the main factor affecting development in the current trial, we may also have expected to see taller plants in the lit treatments (due to the temperature lift), but this was not observed.

In the previous work, light levels of 2.5 klx were used for 12 hours/day, and the extended duration of lighting (16 h), together with the higher levels applied in the current trial (3 klx), may have contributed to the observed reductions in duration, since development was shown to be more sensitive to temperature at higher light levels (MAFF project HH1308TPC).

In the current study, it is unlikely that the canopy temperatures were markedly warmer in the lit than in the ambient light treatments, since the increased transpiration and evaporative cooling under the lights would would be expected to offset any heat gain which may otherwise occur. There would certainly not be anything like the temperature differences applied in PC 80a (10°C range), suggesting that crop duration was probably affected in a more subtle way by the interactions between light integral, CO_2 and temperature. Having said this, the increased bud development observed in the lit treatments in the current trial may well have been due to small temperature differences, since this process has been shown to be very sensitive to increases in temperature between 15-20°C (MAFF report HH1308TPC).

The fact that there were marked reductions in duration, and increased bud numbers under elevated CO_2 without assimilation lights, would indicate either: that the meristem temperature was warmer due to reduced stomatal conductance and transpiration in elevated CO_2, or that increased assimilate availability in the CO_2-enriched environment drove reproductive development earlier than in the control. Without more detailed work on canopy temperatures under lights, and development in relation to canopy temperature and gas exchange, firm conclusions cannot be drawn.

Table 1: Effects of supplementary lighting and elevated CO_2 on crop duration in early-season New Guinea Impatiens (days from potting).

	Lighting treatment	
CO_2 treatment	**Ambient**	**Ambient + 3 klx supplementary**
Ambient	90.2	75.0
Elevated (set point of 1000 ppm)	82.7	73.3
5% LSD (20 d.f.):	1.475 (when comparing means within lighting / CO_2 treatments)	
5% LSD (3 d.f.):	1.664 (when comparing means between lighting / CO_2 treatments)	

2.4.3.2: Effects of supplementary lighting and elevated CO_2 on plant height, spread and dry weight:

Production using CO_2-enrichment and lighting resulted in more compact plants, and with increased dry matter (Tables 2 and 3; Appendix 4, Figs. 1b & c). Providing an additional 2.16 mol/m^{2}day suppressed internode extension and stretch which would normally be seen if spacing is delayed during the early part of the season when ambient light levels are low. The appearance of the plants was acceptable across all treatments, but when produced under assimilation lighting / CO_2, the proportions of the plant in relation to pot size was good. There were no significant effects of the applied treatments on the number of main branches per plant (Appendix 4, Fig. 3a), and controlled-environment research at Reading University on the effects of elevated CO_2 and supplementary lighting, also indicated that there were no significant effects of CO_2-enrichment on branch number, leaf number or leaf area (Smith & Pearson, *pers. Comm.*). The observed increases in dry weight may be due to increased allocation of assimilate to buds than to stems or leaves as was observed in the Reading work (see also section 2.4.3.3 below).

There were no significant effects of any treatment on mean plant spread (Table 2). Analysis of the standard deviation in data for plant height and spread also indicated that variability in these factors was reduced in plants which had been grown using assimilation lights.

The implications of this are that, by using assimilation lighting (with or without elevated CO_2), growers could expect to achieve more uniform early-season crops without the need for any chemical regulation to control growth.

Table 2: Effects of supplementary lighting and elevated CO_2 on plant height and spread in early-season New Guinea Impatiens.

	Height (cm from bench)		Spread (cm)	
CO_2 treatment	**Ambient**	**Ambient + 3 klx**	**Ambient**	**Ambient + 3 klx**
Ambient	29.8	26.5	32.9	33.4
Elevated (set point of 1000 ppm)	26.9	24.9	31.4	31.3
5% LSD (20 d.f., within treatment comparisons):	0.57		0.98	
5% LSD (3 d.f. between treatment comparisons):	1.67		1.99	

Plant dry weight was significantly increased both by supplementary lighting and elevated CO_2. Under ambient light levels, simply applying elevated CO_2 stimulated a 17% increase in plant dry weight. Under ambient CO_2 conditions, the use of 3 klx supplementary lighting added 21% dry matter compared to the ambient control. From this, it is clear that growers who do not have lighting installed over their crop can theoretically achieve nearly the same levels of increased plant bulk using elevated CO_2 as those who are currently able to use lighting. However, the combination of lighting and CO_2 provided increases of 33% compared to the control, together with a two week reduction in crop duration (Table 3; Appendix 4, Fig. 2).

The increases in plant dry weight presented in the first part of Table 3 represent the direct comparison of dry weights against the control, but do not take into account the differences in crop duration. When this was done, the increases in dry weight in the high light and CO_2 treatments, which had the shortest crop duration, were magnified. When expressed in terms of a rate, dry matter production in plants produced using supplementary lighting and elevated CO_2 was up to 63% higher per unit time than in the control treatment plants. Previous research at Reading University also suggested that dry weight was increased in elevated CO_2, with the main effect on floral dry weights due to increased bud numbers (Smith & Pearson, *pers. comm.*)

Table 3: Effects of supplementary lighting and elevated CO_2 on above pot plant dry weight in early-season New Guinea Impatiens.

	Dry weight (g)		Rate of dry matter accumulation (g/day * 100)	
CO_2 treatment	**Ambient**	**Ambient + 3 klx**	**Ambient**	**Ambient + 3 klx**
Ambient	7.48	9.04 (+ 21%)	8.29	12.05 (+ 45%)
Elevated (set point of 1000 ppm)	8.75 (+17%)	9.93 (+ 33%)	10.58 (+ 28%)	13.50 (+63%)
5% LSD (20 d.f., within treatment comparisons):	0.71		-	
5% LSD (3 d.f. between treatment comparisons):	0.84		-	

2.4.3.3 Effects of supplementary lighting and elevated CO_2 on bud and flower numbers:

Since plants were marketed at a defined flowering stage (4 open flowers), one would not expect there to be any treatment effects on number of open flowers at marketing, but rather differences in other factors such as duration, plant bulk etc. However, the data indicates that there were slightly more open flowers per plant (significant at P = 0.05) in the supplementary light and CO_2-enriched treatments (Table 4), possibly due to the fact that the rate of flower opening was higher in those treatments (Tables 5 & 6). Plants in the elevated CO_2 and light treatments had marginally smaller flowers than in ambient-grown plants (reductions in diameter of 1–2 mm, or 4.6%), which may be associated with assimilate limitation to the larger numbers of developing buds in these treatments as previously suggested in the MAFF trial (HH1308TPC).

By far the most important impact of elevated CO_2 and supplementary lighting on plant development was the large increase in bud number observed in these treatments. Although the use of supplementary lighting stimulated a 20% increase in bud numbers compared to the ambient control (significant at P = 0.01), elevated CO_2 had more marked effects than lighting. CO_2-enrichment with the set point of 1000 ppm, without the use of additional lighting, resulted in a 42% increase in bud number, and there were no further increases in bud numbers when a combination of CO_2 and supplementary lighting were applied (Table 4 & Appendix 4, Fig. 3c). This was surprising due to the fact photosynthesis would probably have been light-limited for much of production, and one would expect the extra dry matter accumulated in the lit treatments to be reflected in increased bud development. There was no evidence to suggest that individual buds were any larger in lit treatments than in the CO_2-enriched plots, which could explain why bud numbers were no higher in the latter.

The increases in bud number/plant in elevated CO_2 production treatments offer the potential for vigorous or extended flowering post-harvest in the absence of adverse conditions that may stimulate premature bud losses or poor bud development.

Table 4: Effects of supplementary lighting and elevated CO_2 on bud and open flower numbers per plant in early-season New Guinea Impatiens.

	Bud numbers		Number of open flowers	
CO_2 treatment	**Ambient**	**Ambient + 3 klx**	**Ambient**	**Ambient + 3 klx**
Ambient	33.0	39.5	4.29	5.20
Elevated (set point of 1000 ppm)	46.9	45.1	4.30	5.88
5% LSD (20 d.f., within treatment comparisons):	5.67		0.991	
5% LSD (3 d.f. between treatment comparisons):	3.98		1.335	

As was mentioned earlier, the reduced duration in the lit treatments, combined with elevated CO_2 was also associated with more rapid flower opening. Data in Table 5 (and Appendix 4, Fig. 4a & b) show that plants in the lit treatments showed first flower at least 13 days earlier than in the ambient light plots, and this was further advanced by 2–3 days by the time 4 flowers were open. Table 6 presents data for the harvest window expressed as the time from the first to fourth flower, with significant reductions in the harvest window in enriched CO_2 (but under ambient light), and in plus/minus CO_2 treatments applied with supplementary lighting. The greatest reduction of 3.3 days was recorded in the plots where both lighting and CO_2 had been applied throughout production.

The ability of growers to define ***both*** the time and duration of flowering is essential if they are to maximize the efficient use of space in the production system. The culture of early-season NGI with elevated CO_2 and lights offers an opportunity for tighter scheduling of high quality, uniform crops than would be possible under ambient conditions.

Table 5: Effects of supplementary lighting and elevated CO_2 on time to first and fourth open flower in early-season New Guinea Impatiens.

	Time to first flower (days from potting)		Time to fourth flower (days from potting)	
CO_2 treatment	**Ambient**	**Ambient + 3 klx**	**Ambient**	**Ambient + 3 klx**
Ambient	83.9	70.5	90.7	74.6
Elevated (set point of 1000 ppm)	78.5	68.9	83.2	72.4
5% LSD (20 d.f., within treatment comparisons):	1.48		1.53	
5% LSD (3 d.f. between treatment comparisons):	3.07		2.73	

Table 6: Effects of supplementary lighting and elevated CO_2 on harvest window expressed as the interval (in days) between the first and fourth flower in early-season New Guinea Impatiens.

	Lighting treatment	
CO_2 treatment	**Ambient**	**Ambient + 3 klx supplementary**
Ambient	6.81	4.15
Elevated (set point of 1000 ppm)	4.71	3.52
5% LSD (20 d.f.):	0.62 (when comparing means within lighting / CO_2 treatments)	
5% LSD (3 d.f.):	0.51 (when comparing means between lighting / CO_2 treatments)	

2.4.3.3. Effects of chemical treatments on flowers and leaves at marketing:

The chemical "flower sticker" treatments had no significant impact on crop duration or development, as they were only applied relatively late in production. However, a commonly reported problem associated with the application of STS as a spray is damage to open flowers and sometimes leaves. Damaged flowers and leaves need to be removed when packing the plants for market, and this represents an increase in labour cost. Consequently, any reductions in requirements for "plant dressing" would be of benefit to the grower.

One of the aims of the current work was to identify whether or not spreading the recommended dose of STS over several applications, rather than making a single application a week before market, would reduce the level of damage. Therefore, STS was applied either at the full rate (2 g/l) a week before, 1 g/l a week and 21 days before, or 0.7 g/l on 3 occasions leading up to marketing. These modifications in application procedure for STS were compared with the effects

of using EthylBloc®, which was applied as a gas, either once at marketing, or twice at bud colour and again at marketing.

In all cases, there was no leaf damage recorded, and the levels of flower damage were low and somewhat variable. This reduced the reliability of the statistical analysis. The data presented in Table 7 indicates that where damage was observed, it was predominantly in the STS-treated plots, with consistently less damage seen in the EthylBloc® or control treatments. The fact that Ethylbloc® is applied as a gas, rather than as a liquid spray onto the leaves, could alleviate problems of damage to delicate structures in the event that the plants are exposed to the scorching effects of the sun, even for brief periods. The disadvantage of applying a gas is its lack of persistence, and this may be important when considering the longevity of the effects of EthylBloc® compared to STS post-harvest.

Table 7: Effects of anti-ethylene agents during production on mean number of damaged flowers / pot in early-season New Guinea Impatiens.

	Control	STS 1	STS 2	STS 3	EthylBloc® 1	EthylBloc® 2
Nº damaged	0.00	0.51	0.04	0.27	0.01	0.02

%5 LSD (20 d.f): 0.227

2.4.3.5 Summary of the main treatment effects at marketing:

Production using 3 klx supplementary lighting (16 hours/day), in combination with elevated CO_2, reduced crop duration by up to 17 days, with elevated CO_2 alone reducing cropping by a week in the absence of additional lighting. The mechanism for reduced duration under lights may be mediated by slightly elevated temperatures, but it is not clear how elevated CO_2 operates to reduce crop time.

Plant dry weight increased by up to 33% when lighting and CO_2 were used together, and even under ambient lighting, enriching with CO_2 stimulated increases of 17%. When expressed as a rate of increase, dry matter accumulation was enhanced by 63% in plants produced with lighting and CO_2.

Production using CO_2-enrichment increased bud numbers per plant by about 40%, with smaller increases (but still significantly higher than in the control), due to assimilation lighting under ambient CO_2 conditions. Under elevated CO_2 bud number did not increase further when assimilation lighting was applied.

The potential for improved scheduling of uniform early-season New Guinea Impatiens was greatest in plots which were produced with supplementary lighting and elevated CO_2, as these factors reduced cropping time, produced more uniform plants, reduced the variability in time to flowering, and compressed the harvest window.

The available data suggest that repeated low doses of STS, or the application of EthylBloc® may cause less flower damage than a single application of STS at the recommended rate. This could have implications for saving labour costs during packing and marketing New Guinea Impatiens.

2.4.4 Ethylene measurements in the transport chain

An objective of the trial was to follow a single batch of plants through the marketing chain. Sainsbury's allowed us access to their distribution network entering at Double H Nurseries Ltd (New Milton), via the Swindon depot and ending at the supermarket at Bracknell. Air samples were collected using Tedlar bags at the following points and times and were analysed at Reading within 24 hours of collection:

26.5.99

In the production area at Double H and at HRI Efford
Boxed product
Plants on wrapped and unwrapped trolleys at Double-H in the loading bay
Shelf life room, Double H
On lorry prior to loading at Double H

27.5.99

On lorry prior to unloading at Homebase Swindon 9.30 am
Diesel exhaust (sampling air direct from exhaust pipe) 9.45 am
On lorry after unloading at Homebase Swindon 10.15 am
On trolley in distribution centre at Homebase Swindon 10.00 am
Unloading area at Homebase Swindon 2.15 pm
Plant storage area at Homebase Swindon 2.00 pm
On lorry prior to despatch from Homebase Swindon 3.30 pm

28.5.99

On lorry after unloading at Sainsbury's Bracknell 12.00 noon
Plant display area in Sainsbury's Bracknell 12.15 pm
In Banana display area at Sainsbury's Bracknell 12.40 pm
In storage area prior to putting on shelves (in this area the plants were stored for a few hours before going into the shop, the trolley was right next to a stack of bananas in crates) 12.50 pm

The integrity of the Tedlar bags was tested by injecting known ethylene concentrations and analysing the contents at several time points thereafter up to 48 hours. The data showed that there were no reductions in ethylene concentration over the period which would elapse between sampling and analysis during the current trial.

The ethylene analysis results are presented in Table 8. Of those listed above, only samples in which ethylene was detected have been included in the table.

Table 8: Ethylene peaks in samples collected during the transport and distribution chain.

Sample	Peak Height mm	Mean	Ethylene conc. nl/ml	ppm ethylene
Diesel exhaust 27.5.99	6 6 6	6	0.045	0.05
Holding area - Sainsburys Bracknell 28.5.99	2 2 1.5	1.8	0.014	0.01
Banana pile 28.5.99	1 1.5 1	1.2	0.009	0.01

From the rather limited data set available from the current trial, it was apparent that damaging ethylene concentration were not present at the time samples were collected in any of the environments above. Even diesel exhaust fumes, and piles of bananas which have been reported as being the most significant sources of ethylene, contained only 0.05 and 0.01 ppm ethylene (respectively) in the samples collected.

There must be times, or specific combinations of environmental and crop-specific factors (stage of development), that will be critical to avoid, as they can promote either increased ethylene levels, or enhanced sensitivity, but these conditions were not encountered in the current investigation.

There is a need for more information on ethylene, i.e. its behaviour in air. The only time consistent levels of ethylene were measured were the Efford shelf life rooms with a completely sealed environment. But even in that environment, levels gradually decreased over time (see Table 10). Such a sealed environment is never really replicated in a transport chain. Even on a trolley, or in the back of a lorry there would be some ventilation. Ethylene is highly volatile, of low density, and does not remain for long if it has anywhere to escape. The other area that requires more information is the times of maximum ethylene release in the life of the crop.

Tests which included a mixture of ripe fruits in boxes of plants have shown that even in this environment ethylene production was not guaranteed, and was possibly linked to the developmental stage of the fruit. The fruit had been purchased in the supermarket, and by that stage, may have already undergone all changes during which ethylene would have been produced. This implies that ethylene evolution from fruits may well occur primarily during transport as the fruits ripen immediately pre-sale, which would present a significant risk to pot plants in a mixed load.

Another test conducted at Efford involved leaving NGI plants in sealed boxes in the shelf life room overnight, and on that occasion, reasonable ethylene levels were measured, though differences in plant development in this study may have influenced the levels of ethylene recorded.

There is a need for work on ornamentals with detailed studies to identify the critical periods of plant development/senescence when ethylene evolution and sensitivity to ethylene occurs.

2.4.5 Post-harvest data

Following production under different light and CO_2 regimes, and with a variety of chemical anti-ethylene treatments, 8 representative pots were removed from each plot at marketing. Of these, 4 were exposed to ethylene for 4 hours (as described earlier) and the other 4 remained untreated. After the pots had been exposed to ethylene, all plants were transferred to the home-life environment for 4 weeks' post-harvest assessment.

In order to highlight the main effects of treatments during the post-harvest phase, the statistical interpretation has been presented in graphs and tables in the text as appropriate. In each case, the table / graph shows which treatment had the main effect on the variable in question i.e. when light dominated the way flowers performed post-harvest, the graph presents the effects of light, rather than presenting all treatments together and masking the main results. The impact of each treatment on a particular variable is presented in Appendix 5, Figs. 1 – 6, where complete data sets are presented graphically.

2.4.5.1 Effects of treatments on post-harvest open flower number.

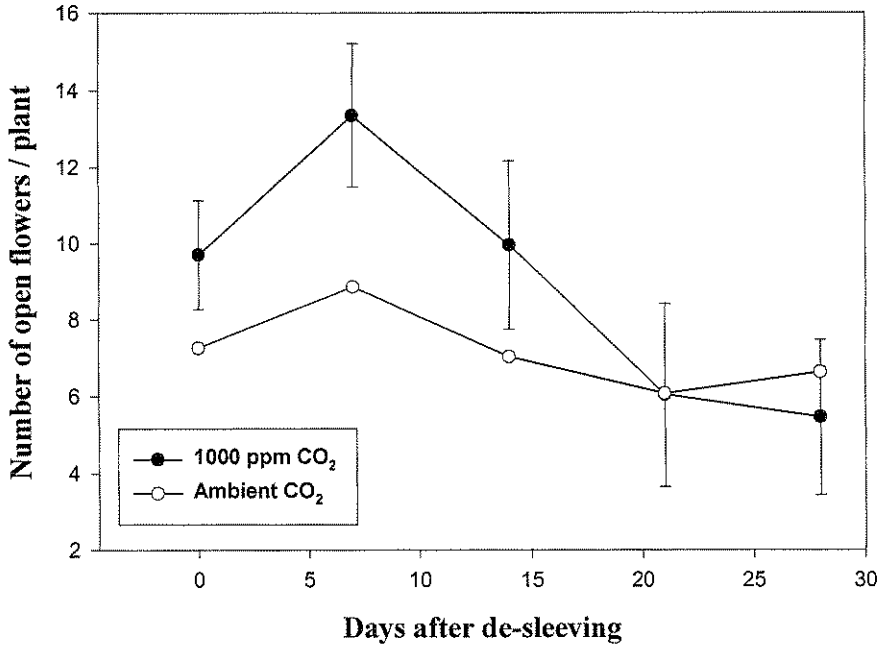
Differences in number of open flowers/plant at marketing were small, since plants were selected when they had 4 open flowers. There were, however, significantly more buds on plants produced at elevated CO_2 and with supplementary light, and the results show that at least a proportion of the extra buds continued to develop and open post-harvest.

The increase in number of open flowers during the retail phase (sleeved) was calculated as the difference between open flowers at marketing and de-sleeving. Plants which had been produced under elevated CO_2 conditions showed 75% more flower opening during the sleeved phase

(significant at P = 0.05), with supplementary light increasing flower opening by 43%. This increase in flower opening whilst the plant is sleeved could be beneficial in terms of consumer appeal, with a more colourful product (plus more buds to come) being easier to sell in the market than plants with fewer open flowers.

The main production factor influencing the number of open flowers post-harvest was CO_2-enrichment, with 34% more open flowers in plants produced with 1000 ppm CO_2 compared to those grown under ambient CO_2 conditions (Fig. 3). The difference in open flower number between CO_2 treatments increased to 51% one week after de-sleeving, representing considerably greater flowering impact to the consumer. Beyond 2 weeks after de-sleeving, the benefits of production at elevated CO_2 declined, so that by the end of the third week, there were no significant differences in open flower numbers on plants which had been produced in either CO_2 environment.

Figure 3: Effects of CO2 enrichment during production on the number of open flowers post-harvest in New Guinea Impatiens (± 5% L.S.D; 3 d.f.)

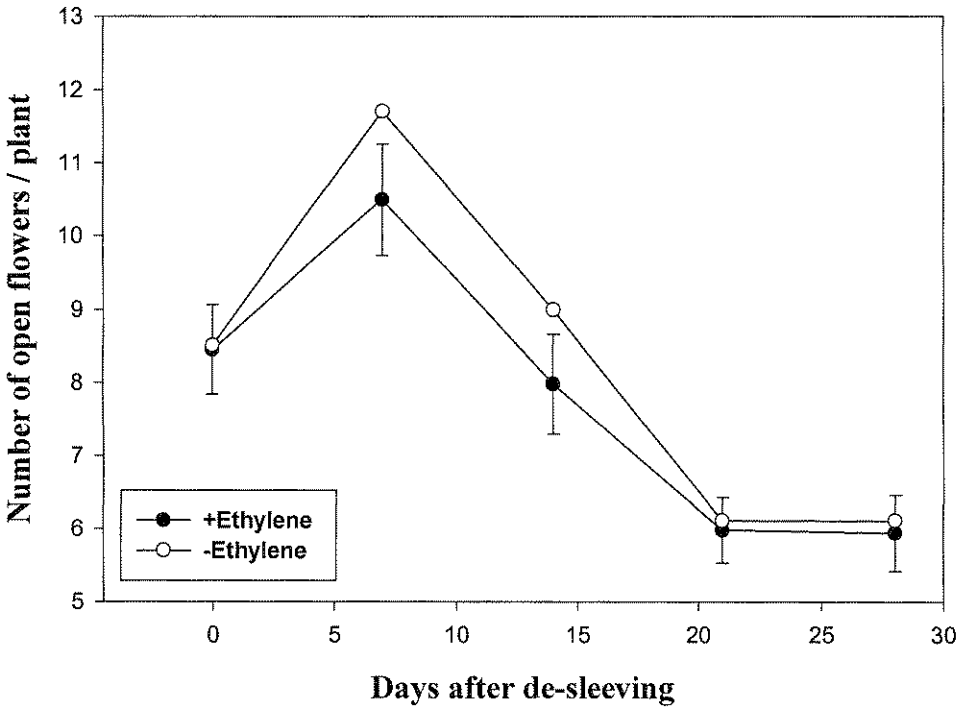


The data suggest that production of early-season New Guinea Impatiens using elevated CO_2, either with or without supplementary lighting (see Appendix 5; Fig 1), would provide added value in terms of increased flowering post-harvest.

It must be emphasised that the importance of supplementary lighting in maintaining the CO_2 enhanced flowering will increase in locations where ambient light levels during the early part of the season are lower than those received at HRI Efford.

The second important factor affecting open flower numbers post-harvest was exposure to ethylene. The data showed that there were no significant differences between the numbers of open flowers in either treatment at de-sleeving (Fig. 4), but that a week later, there were only 12% fewer flowers on plants which had been treated with ethylene. This was not expected, as previous work in this area (Dostal *et al.*, 1991) suggested that up to 80% of flowers and buds were lost following a 4 hour exposure to 1 ppm ethylene. The research by Dostal *et al.* exposed New Guinea Impatiens to ethylene at a temperature of 23°C. In the current trial, exposure was at 18 – 20°C to simulate normal ambient supermarket conditions. Previous research has demonstrated that plants may differ in their sensitivity to ethylene at different temperatures (Reid, 1989; Abeles *et al*, 1992), and it may be that at 23°C NGI are more sensitive to ethylene than at 18–20°C. If this is the case, then new guineas will only be at risk from ethylene when transported or displayed under certain conditions. The highest risk period would be in the summer months, when plants may be stood in a warm, enclosed space for several hours, or when the transport temperatures are not controlled.

Figure 4: Effect of ethylene exposure at marketing on the number of open flowers post-harvest in new guinea impatiens (± 5% L.S.D; 3 d.f.)



Further research would be required to assess the effects of changes in temperature and possibly humidity on the sensitivity of New Guinea Impatiens to ethylene.

2.4.5.2 Effects of treatments on flower loss post-harvest.

Graphs in Fig. 5 a & b present the main effects of CO_2 and light respectively on post-harvest flower losses, with the effects of anti-ethylene agents presented in Fig. 6 (graphs in Appendix 5, Fig. 2 can also be referred to).

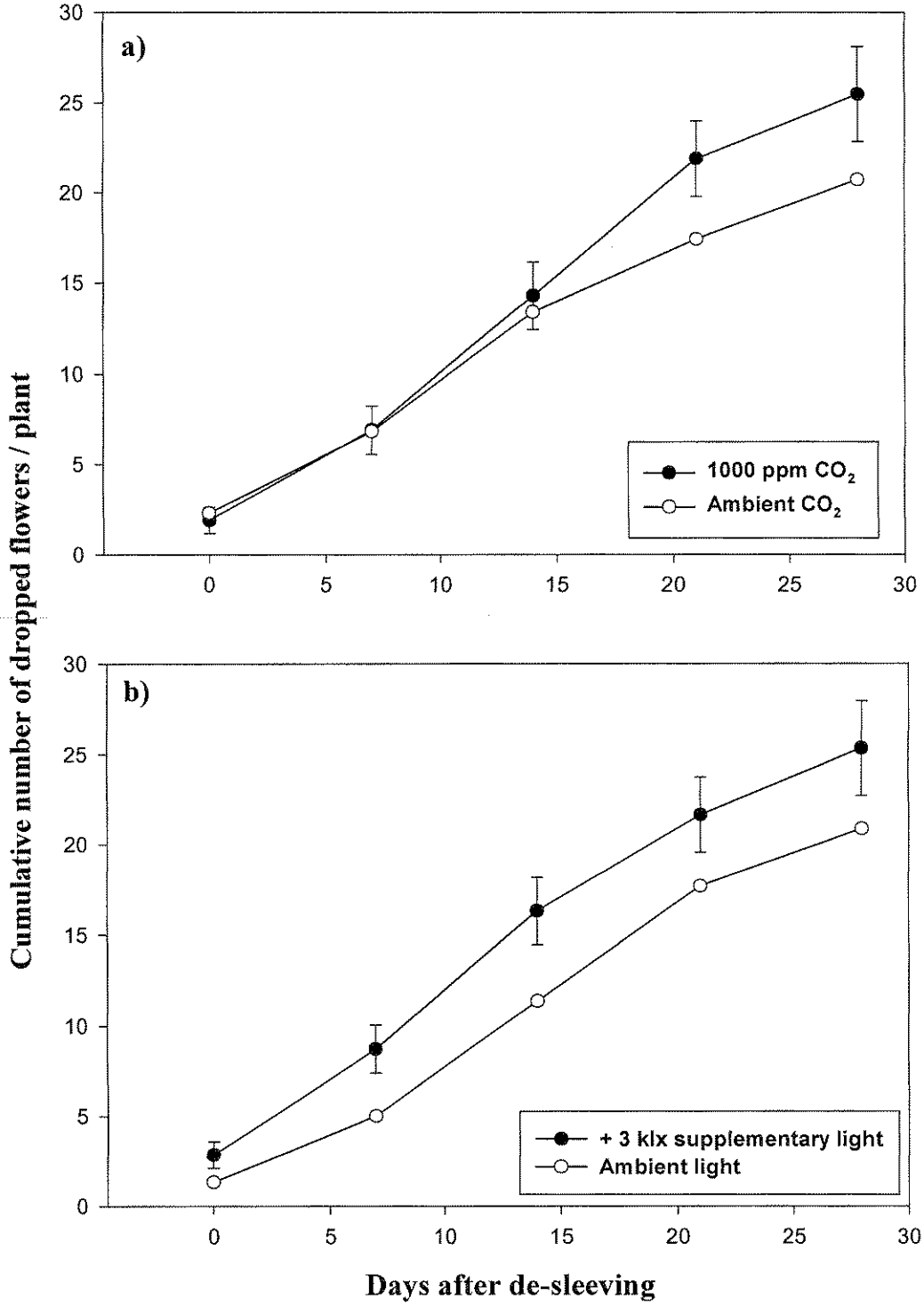
Data in Fig. 5 a & b show that using CO_2-enrichment and supplementary lighting during production resulted in increased flower losses post-harvest, although the increased losses in the elevated CO_2 treatments were not significant until 3 weeks after de-sleeving. However, the flower losses from plants in the supplementary light treatments were consistently higher (significant at $P = 0.05$) than in those produced under ambient light conditions.

Despite the increase in flower loss in the elevated CO_2 production treatments, there were still more open flowers per plant right up until 3 weeks post-harvest (Figure 3), whereas, the benefits of supplementary lighting were lost after only 2 weeks post de-sleeving. These results reflect the marked increase in flower bud number in these treatments, compared to the control.

The enhanced flower losses in the supplementary lighting treatments may be due in part to the inability of plants to acclimatise from the production lighting regime to the relatively dim post-harvest environment, and this may be compounded by the low nutrient availability in the lit treatments at the end of production. Data for the media analysis (Appendix 6) show that e.c. declined in the lit treatments at both CO_2 concentrations, with depletion of nitrogen in the media. The trends for flower (and bud) losses in the ambient light treatments were the same as in the supplementary lighting regimes (Appendix 5; Figs. 2 & 4), so the main conclusions drawn from the trial still hold despite the implications of nutrition. Any benefits of production using supplementary lighting and elevated CO_2 might be further enhanced with an increase in nutrition towards the end of production, but this needs further investigation.

The impact of production light levels on post-harvest performance in various light environments is an important issue, and further work is required to study this in detail for a range of commercially important ornamental pot plant species.

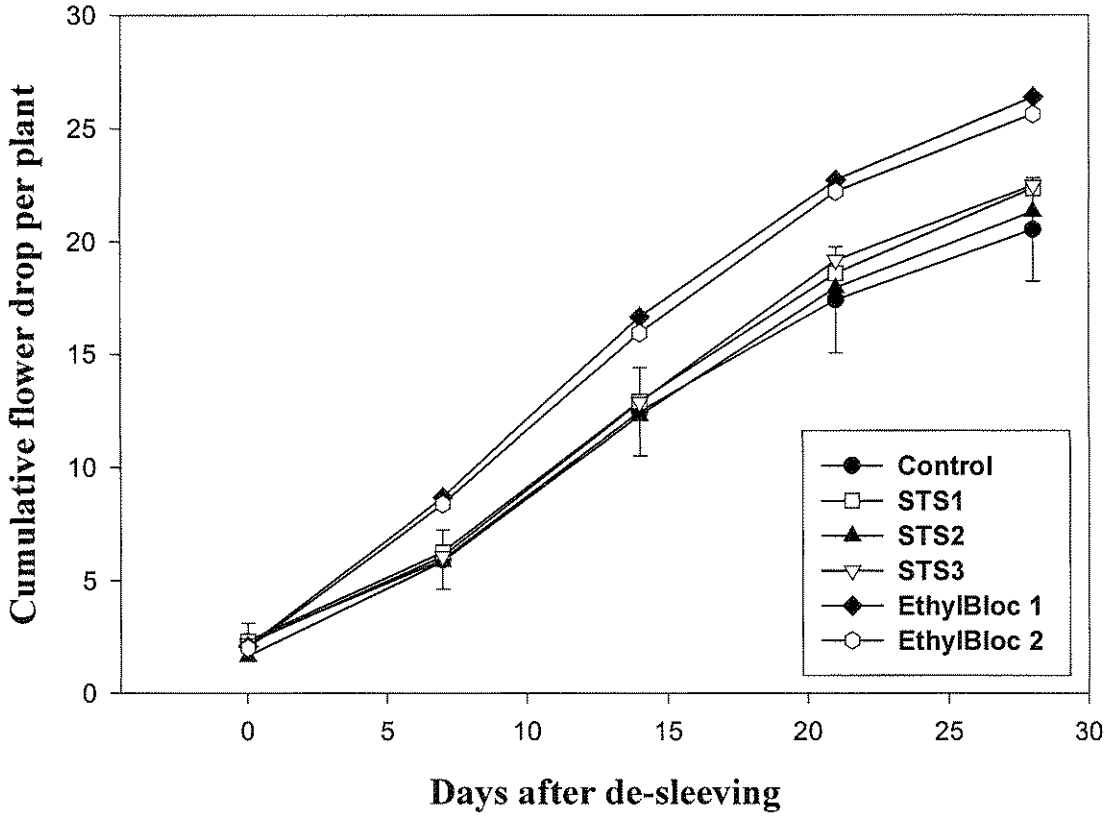
Figure 5: **Effects of CO2 enrichment (a) and supplementary lighting (b) during production on the number of dropped flowers post-harvest in new guinea impatiens (± 5% L.S.D; 3 d.f.)**



In addition to the effects of light and CO_2, there were also significant effects of the anti-ethylene agents on cumulative flower drop (Fig. 6 and Appendix 5, Fig. 2). At de-sleeving, there were no significant effects of chemical treatments on flower loss, but both EthylBloc® treatments resulted in significantly higher flower losses from one week after de-sleeving. After that time, the lines ran parallel to other treatments, suggesting that increased losses associated with the EthylBloc® treatment were short-lived. From the graph, the data also suggest that the use of STS as applied in the current trial did not reduce flower loss compared to the control, but this may relate to the insensitivity of the plants to the ethylene applied rather than to low efficacy of the STS treatment (ie they did not lose flowers even when exposed to ethylene, so STS had no benefit).

Subsequent trials with EthylBloc® indicated that this product was in fact effective in reducing both flower and bud losses (see section 2.4.6). The reason for the lack of efficacy of EthylBloc® in reducing flower losses in the main trial may be due to the large number of plants in the chamber, and the high humidity (due to the water seal at the base), which may have been deleterious to flower longevity. Further testing would be necessary to confirm this.

Figure 6: Effect of chemical treatments at marketing on post-harvest flower loss in New Guinea Impatiens (± 5% L.S.D; 20 d.f.)

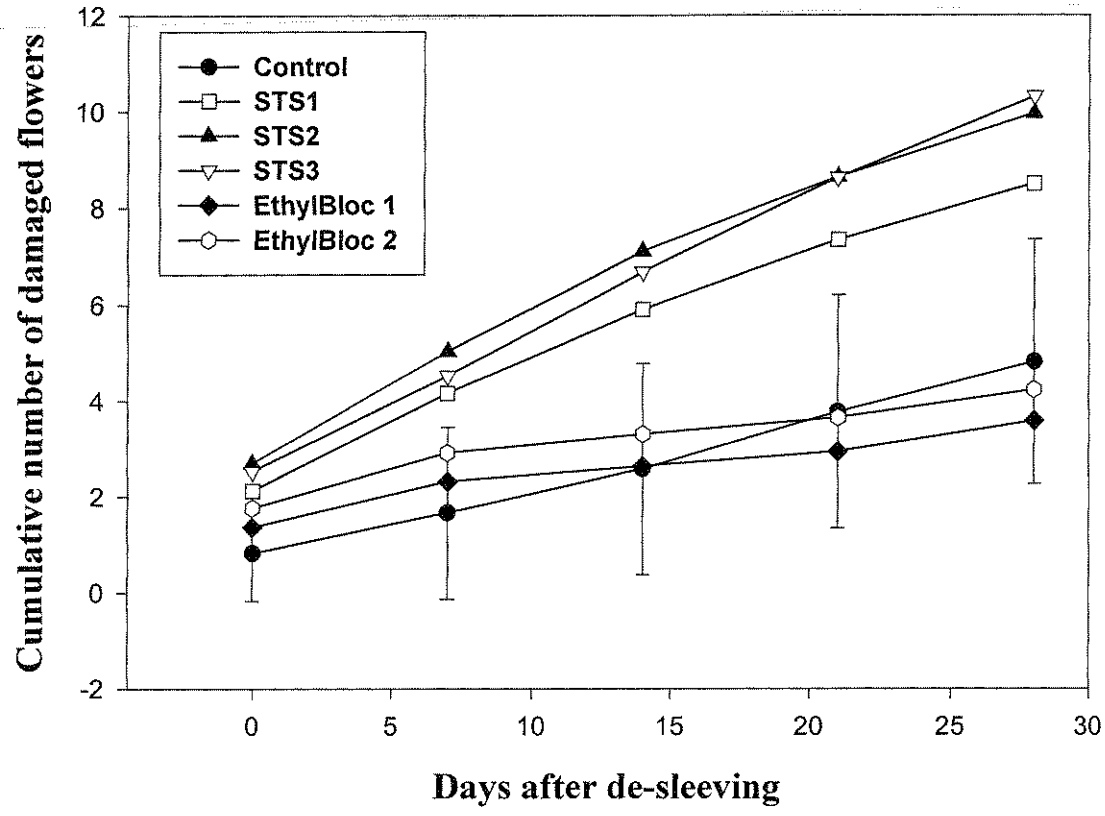


2.4.5.3 Effects of treatments on flower damage post-harvest.

Flower damage was assessed according to the presence of visible premature petal lesions due to physiological deterioration of the flowers rather than physical damage which may appear in more bulky plants when packaged in a standard sleeve. The data showed that flower damage was increased slightly in the lit and elevated CO_2 treatments (Appendix 5, Fig. 3), and this appeared to be related mainly to the effects of the STS treatment, where significantly higher levels of flower damage post-harvest occurred than in either the controls or the EthylBloc® treatments. The fact that STS damage appeared more prevalent in the lit treatment may be a misleading result, since application of STS occurred when the lights were still on, which may have been enough to promote damage. This highlights the need for care in the application of STS.

The fact that damage in the STS treatments diverged from the control and EthylBloc® treatments suggest that the damage due to STS did not decline during shelf-life, but was magnified.

Figure 7: Effect of chemical treatments at marketing on number of flowers showing damage post-harvest (± 5% L.S.D; 20 d.f.)

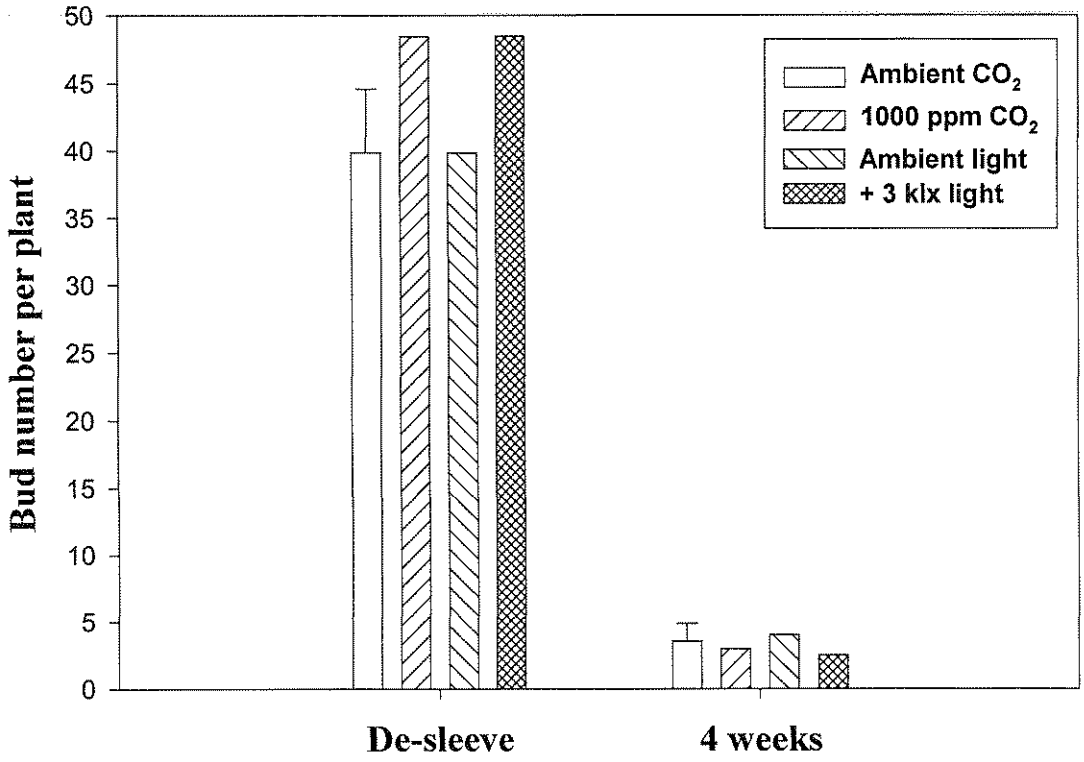


2.4.5.4 Effects of treatments on bud numbers and bud losses post-harvest.

Increases in bud numbers in each treatment from marketing to de-sleeving were calculated in the same way as increases in flower numbers. The most marked increases in bud number during this phase were on plants produced under lighting, with 120-fold increases in bud number compared to ambient-grown plants (increases of 0.06 and 7.32 buds respectively; 5% L.S.D = 2.37 (3 d.f.)). In the same way that CO_2 and supplementary light increased the numbers of open flowers, greater bud numbers at this stage may also improve the plants' appeal in the market place.

The effects of 1000 ppm CO_2 and supplementary light on bud numbers at de-sleeving and at the end of shelf-life are presented in Fig. 8. As at marketing, both elevated CO_2 and supplementary lighting treatments alone stimulated significantly more buds per plant than in the ambient treatments early on post-harvest, but no further increase when used together. However, buds losses were also increased in these treatments, so that, by the end of shelf-life there were no significant differences in bud numbers between lighting or CO_2 treatments.

Figure 8: Effect of CO2 enrichment and supplementary lighting during production on bud numbers post-harvest (± 5% L.S.D; 3 d.f.)



The advantage in terms of increased flower and bud numbers in the CO_2-enriched and lit treatments had to be considered alongside the higher levels of bud losses recorded in these

treatments, and particularly for plants grown with supplementary lights (Table 9). As bud and flower numbers were not lower in these treatments by the end of the post-harvest phase, it would suggest that the increased numbers of buds at marketing did in fact offset the losses incurred.

The analyses also highlighted a significant interaction between production of plants using assimilation lighting and ethylene treatment, with plants in the lit treatments exhibiting increased buds losses following ethylene exposure compared to those produced in ambient-light. These data suggest that the sensitivity of plants to ethylene may be enhanced following production with supplementary lighting, and trials which study ethylene sensitivity under different lighting regimes would be required to test this idea. If proved correct, the industry would need to target anti-ethylene treatments at particular times of year in relation to production light levels in order to optimise their beneficial effects.

Although this work identified the benefits of supplementary lighting and CO_2, particularly for increased flower/bud number at marketing, the consumer would also see a relatively high proportion of these dropping off which could be perceived as a negative point (despite the other benefits). Therefore, it will be important for the industry to be able to produce plants ***both*** with more flowers, and with better bud and flower retention.

Again, the reason for the increased flower/bud losses may relate to the problems of acclimation of plants produced under assimilation lights to low irradiance home-environments, but this, together with work on the possible interactions between production lighting and ethylene sensitivity will require further research.

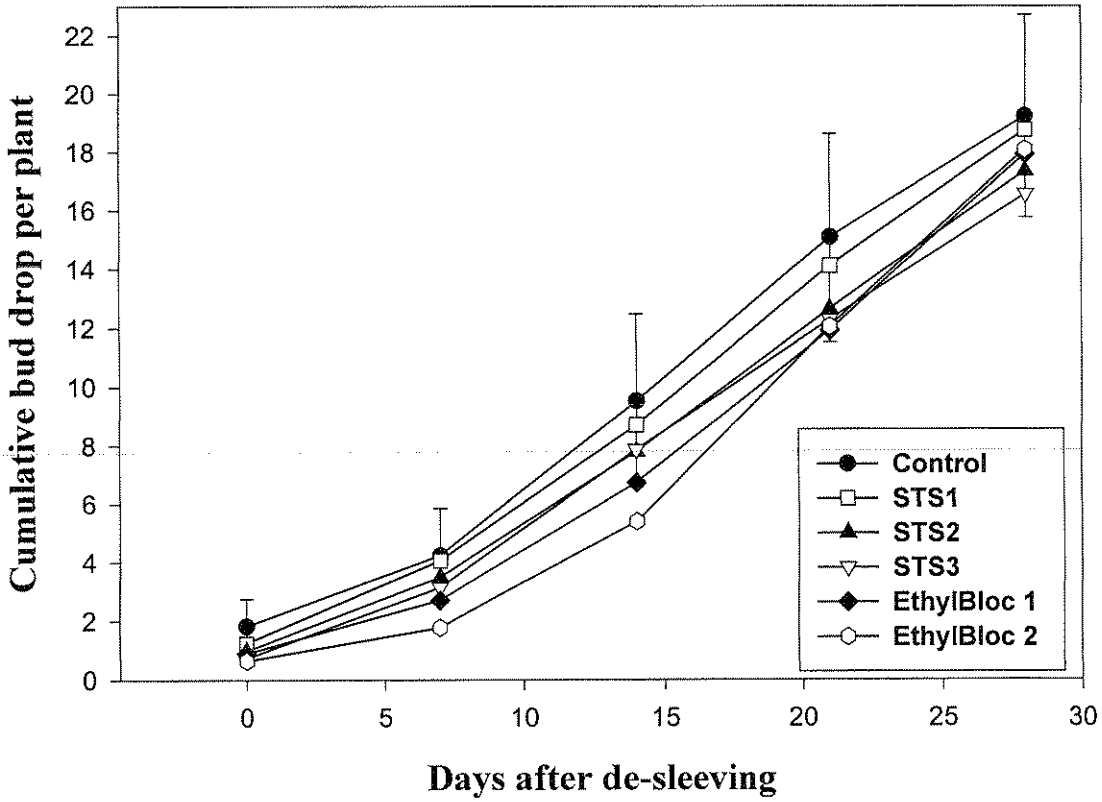
Table 9: Effects of production lighting treatment on post-harvest bud losses in New Guinea Impatiens.

Time post-harvest	Lighting treatment		5% L.S.D (3 d.f.)
	Ambient	Supplementary	
De-sleeve	0.52	1.58	0.43
7 days	1.65	4.82	0.87
14 days	4.71	10.62	2.52
21 days	9.60	16.42	3.96
28 days	12.90	23.03	4.34

When the effects of anti-ethylene chemicals on bud loss were analysed, it was apparent that for the first two weeks after de-sleeving, treatment with EthylBloc® (especially when 2 applications were used), resulted in significant reductions in bud loss compared to both untreated controls and STS-treated plants (Fig. 9 and Appendix 5, Fig. 4). The additional work with EthylBloc® (see section

2.4.6) also reinforced the observation that this product was effective in promoting bud retention during the retail and early home-life phases, suggesting that treatment of plants with EthylBloc® would be important to maintain buds for the consumer (see Elgar *et al.*, 1999).

Figure 9: Effect of anti-ethylene chemical treatments at marketing on post-harvest bud losses in New Guinea Impatiens (± 5% L.S.D; 20 d.f.)



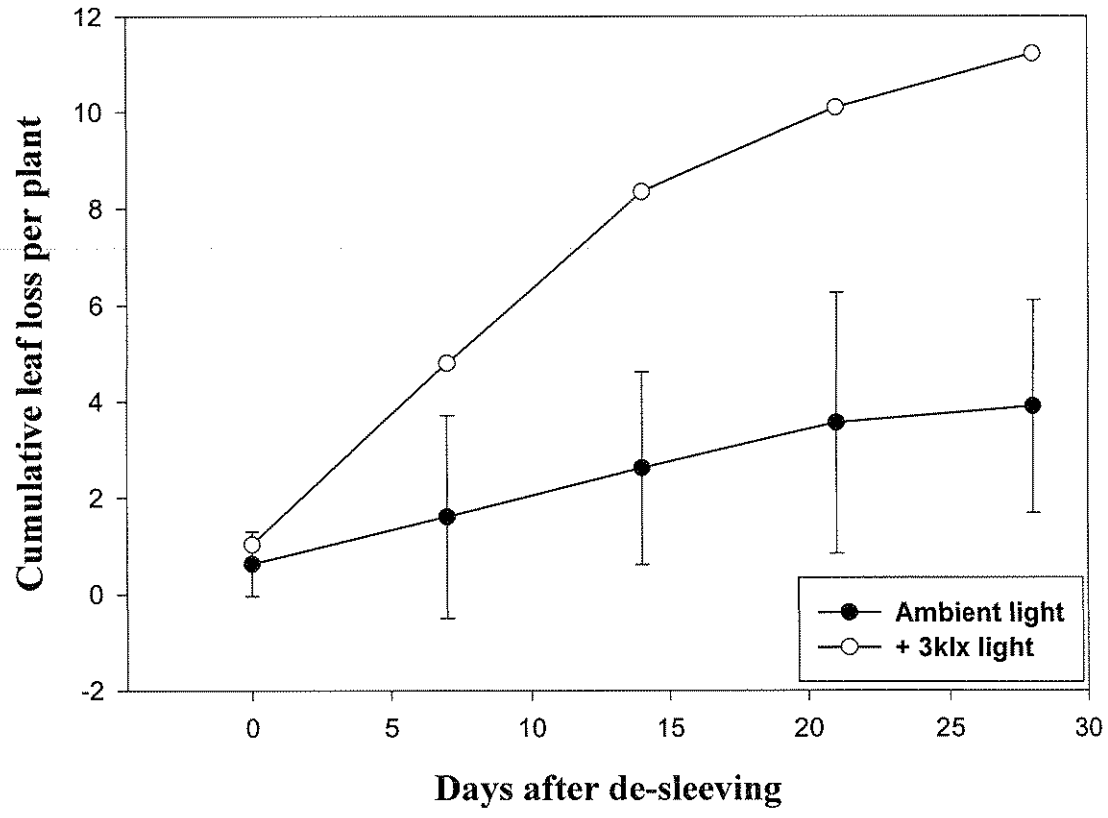
2.4.5.5 Effects of treatments on leaf losses and damage post-harvest.

There were small increases in leaf losses at de-sleeving in plants which had been exposed to ethylene, but at this stage, there were no significant effects of CO_2 or lighting treatment. However, production lighting treatment was the major factor in post-harvest leaf losses, with plants produced using supplementary lights showing significantly higher levels of leaf drop than those produced under ambient lighting conditions (Fig. 10 and Appendix 5, Fig. 5). It was also apparent that 2 weeks after de-sleeving, plants produced at elevated CO_2 at both light levels were beginning to lose more leaves than the controls.

These effects could result from two factors. Firstly, the denser canopy produced under high light and CO_2 conditions may have senesced prematurely under the low-light levels in the post-harvest environment, with the lower canopy leaves dropped first as would be expected in dense foliage which had not adapted to dull environments. Secondly, depleted nutrient availability in the media of plants produced with supplementary light and CO_2 could result in earlier leaf losses than might be seen in plants with more resources available.

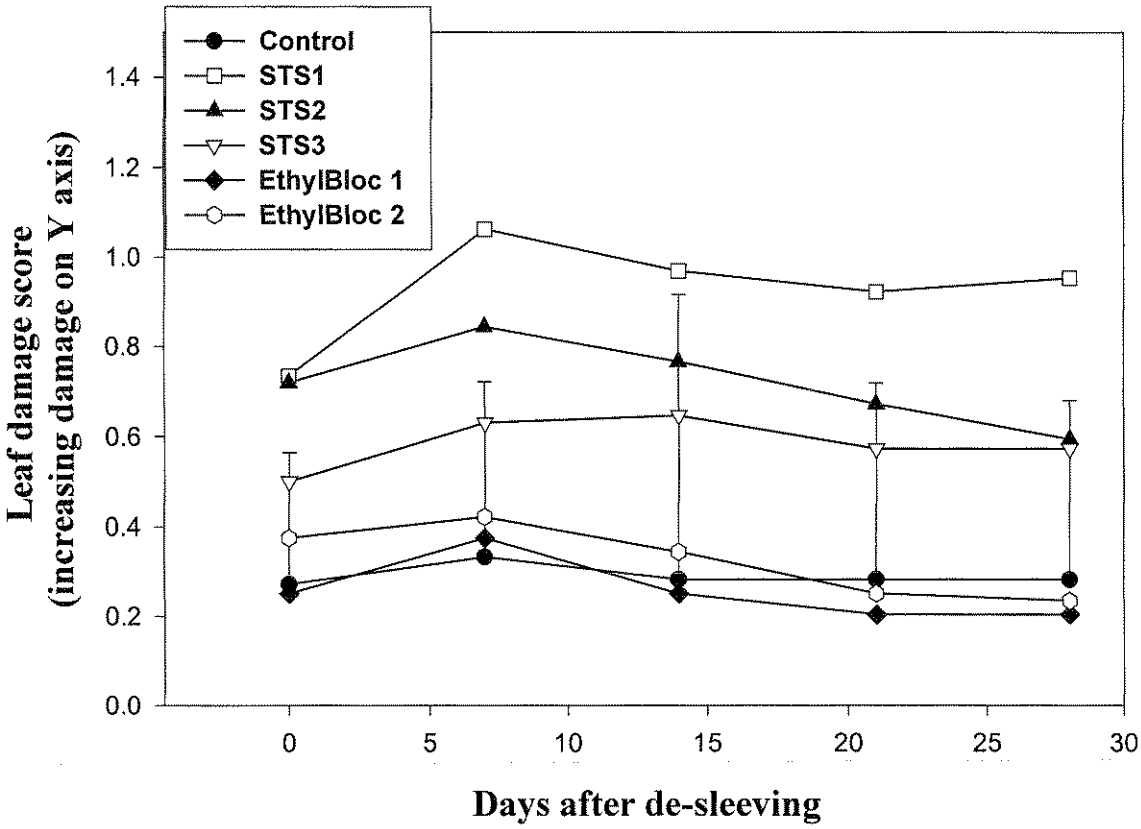
Future work on production nutrition and the use of supplementary feeds post-harvest could address this question.

Figure 10: Effects of supplementary lighting during production on the number of dropped leaves post-harvest in New Guinea Impatiens (± 5% L.S.D; 3 d.f)



In much the same way as flower damage, leaf damage was affected by chemical treatment rather than production environment (Fig. 11 and Appendix 5, Fig. 6). Overall, incidence of leaf damage was low, and although damage in the STS plots proved significant, there was variability in the data and results need treating with caution.

Figure 11: Effect of chemical treatments at marketing on post-harvest leaf damage score in New Guinea Impatiens (+ 5% L.S.D; 20 d.f)



2.4.6 Results of an additional trial to test the extent of the longevity of effects of EthylBloc®

Data presented in Fig. 12 show the effects of ethylene exposure with and without pre-treatment with the anti-ethylene agent EthylBloc®. The data indicate two main features of the EthylBloc® treatment.

Firstly, it was effective for the first week post-sleeving, and as such, would ensure that the plants perform well through the transport and marketing chain. Six days after sleeving, treatment with EthylBloc® had reduced flower and bud losses by ≈ 70% and 95% respectively. However, beyond a week from sleeving, the beneficial effects of EthylBloc® were lost. The short-term benefits of EthlyBloc® have also been published by Reid *et al.* (1999), and have been attributed to the fact that treatment using transient gaseous product would not have the persistence of other anti-ethylene agents such as STS. However, EthylBloc® was recommended as an excellent product for ensuring safe passage of plant material from the grower to the consumer.

Secondly, in pots which had not been treated with EthylBloc®, flower and bud losses were no greater following ethylene exposure compared to control plants. The was extremely surprising in light of published work (Dostal *et al.*, 1991) reporting the extreme sensitivity of New Guinea Impatiens to exogenous ethylene applied at 1 ppmv. In the current trial, air samples were taken at hourly intervals during ethylene exposure, and analysis of the samples revealed that 2.55 – 3.0 ppmv ethylene had been present throughout (see Table 10 below). As discussed earlier, Dostal's exposure technique was at 23°C, and this may have influenced the results differently from the 18-20°C exposure temperature used in the current trial.

These data suggest that it may not purely be the level of ethylene to which the plants were exposed which governed the plant's response, but a combination of factors including:- the sensitivity of the plant to ethylene at any particular developmental stage, and environmental conditions such as temperature, humidity and light during the time of exposure. During transport, storage and sale, it has been shown that a plant's sensitivity to ethylene can be reduced at lower temperatures. Although it is not always practical or physiologically possible to transport pot plants at low temperatures, (depending on plant species' tolerance of low temperatures). Further work is required to identify areas for optimising transport and storage conditions for pot plants in relation to ethylene sensitivity.

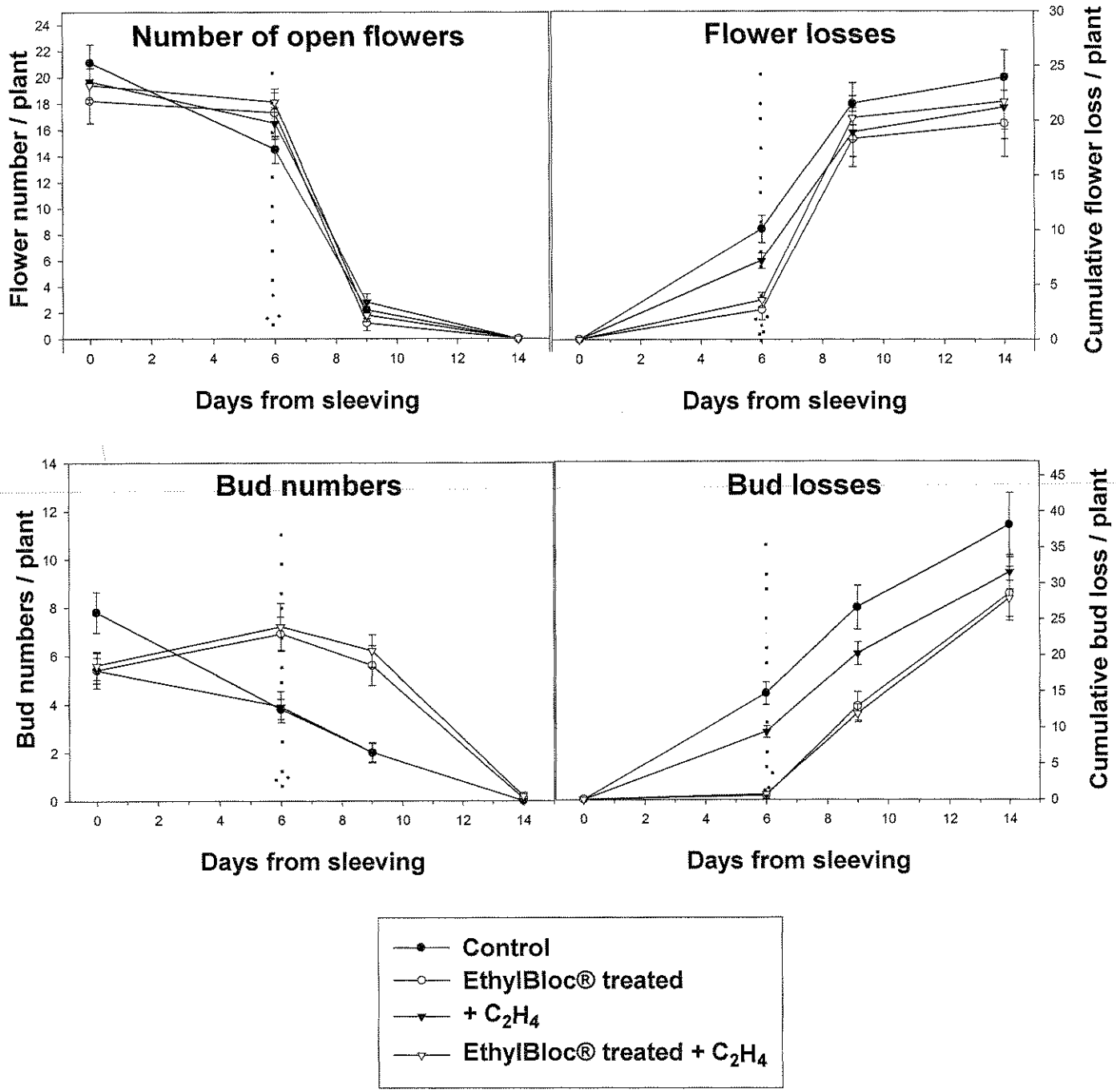
Table 10: Ethylene levels during exposure in the mini-trial

Time after exposure	Ethylene concentration (ppmv)
Background (pre-exposure)	0.00
10 mins	2.93
1 hour	2.83
2 hours	2.75
3 hours	2.59
4 hours	2.56

Figure 12: Effects of EthylBloc® exposure on flower and bud retention in potted New Guinea Impatiens.

Dotted arrow represents time of de-sleeving.

Standard error bars are shown for each data point.



2.5 Conclusions

- For ambient early-season production, there was evidence of CO_2-depletion in the production unit. However enrichment was possible for the majority of the production time, and when vents opened more as light levels increased, CO_2 levels were still running at 500 – 700 ppm. The benefits observed in the high CO_2 treatment suggest that applying CO_2 during early-season production is worthwhile.

- There were several benefits of early-season production using elevated CO_2 and supplementary lighting including up to a 17 day reduction in crop duration, increased plant bulk, more uniform plant height, and increased bud numbers (primarily driven by CO_2 enrichment).

- Production using elevated CO_2 and supplementary lighting reduced variability in time to flowering offering the potential for improved scheduling of the early-season crop.

- Results indicated that production with CO_2-enrichment afforded benefits with or without supplementary lighting, but the importance of light would increase in locations with poor ambient light levels.

- From the available data, there were no indications of high levels of ethylene at any point in the marketing chain, but the need for care under certain conditions was highlighted.

- Application of EthylBloc® at marketing resulted in less flower and leaf damage than using STS, although repeated applications of STS at lower rates leading up to marketing did reduce damage levels. This has implications for reducing labour costs during packing.

- EthylBloc® resulted in significant reductions in bud losses for the first week after marketing, with some evidence for reduced flower loss, suggesting that this product could be recommended as a method for ensuring protection against ethylene damage from nursery to consumer.

- Post-harvest, the effects of using elevated CO_2 and supplementary light during production dominated the plants' post-harvest performance compared to the relatively small effects of applied anti-ethylene chemicals.

- During shelf-life, the benefits of production using elevated CO_2 and supplementary lighting translated into more prolific flowering in the retail phase offering greater impact on the display shelves, and also enhanced flower numbers for up to 3 weeks post de-sleeving.

- While the use of supplementary lighting and CO_2 enrichment led to greater flower and bud numbers per plant at marketing, and even up to 2 weeks post de sleeving, cumulative flower and bud drop was greater at 4 weeks after de-sleeving.

- Manipulation of nutrition and the use of post-harvest feed supplements may improve post-harvest performance in plants grown under lights and with CO_2. Interactions between production and home-life light environments may also be important in the understanding of how to promote post-harvest longevity in these treatments. These aspects need further investigation.

- New Guinea Impatiens was not as sensitive to ethylene exposure as was expected from previously published work, and this highlighted the need for a fuller understanding of which developmental and environmental factors might be most important in relation to the sensitivity of this species to ethylene. For example, transient fluctuations in transport temperature may be a critical factor determining levels of ethylene production / damage.

ACKNOWLEDGEMENTS

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References

Abeles, F.B., Morgan P.W. and Saltveit, M.E. Jr. 1992. Ethylene in plant biology. Edition 2. Academic Press, San Diego, CA.

Beyer E.M. Jr. 1976. A potent inhibitor of ethylene action in plants. *Plant Physiology* **58**, 268 – 271.

Cross E, 1996. Safer alternatives to STS. *Bulletin Pennsylvania Flower Growers*, No. **435**, 1-3

Dostal D.L., Agnew N.H., Gladon R.J. and Weigle J.L., 1991. Ethylene, simulated shipping, STS and AOA affect corolla abscission of New Guinea Impatiens. *Hortscience* **26**, 47-49.

Dupille E, Sisler EC, Ait Oubahou A (ed.) and El Otmani M, 1995. Effects of an ethylene receptor antagonist on plant material. AUSO: Postharvest physiology, pathology and technologies for horticultural commodities: recent advances. Proceedings of an international symposium held at Agadir, Morocco, 16-21 January 1994. 294-301

Elgar HJ, Woolf AB and Bieleski RL. 1999. Ethylene production by three lily species and their response to ethylene exposure. Postharvest Biology and Technology, **16**, 257-267.

Langton FA. 1997. HDC review report PC 134: Ornamentals: A review of the role of ethylene in post harvest flower senescence and abscission and methods to ameliorate ethylene effects. 41 pages

Muller R, Serek M, Sisler EC and Andersen AS, 1997. Post harvest storage quality and rooting ability of Epipremnum pinnatum cuttings after treatment with ethylene action inhibitors. *Journal of Horticultural Science*, **72**: 3, 445-452

Reid M.S. 1989. The role of ethylene in flower senescence. *Acta Horticulturae*, **261**, 157–169.

Reid, MS, Dodge LL and Celikel, FG. 1999. A breakthrough in ethylene protection. *Grower Talks* April 1999, 48, 63

Reid M.S, Paul J.L. and Young R.E. 1980. Effects of ethephon and betacyanin leakage from beet root discs. *Plant Physiology, **66**, 1015-1016.*

Serek M, Sisler EC and Reid MS, 1994. Novel gaseous ethylene binding inhibitor prevents ethylene effects in potted flowering plants. *Journal of the American Society for Horticultural Science*, **119**: 6, 1230-1233

Serek M, Sisler EC and Reid MS, 1995a. Effects of 1 MCP on the vase life and ethylene response of cut flowers. *Plant Growth Regulation*, **16**: 1, 93-97

Serek M , Sisler EC, Reid MS, Ait Oubahou A (ed.) and El Otmani M, 1995b. Use of a novel ethylene inhibitor to increase the life of ethylene sensitive cut flowers and potted plants. Postharvest physiology, pathology and technologies for horticultural commodities: recent advances. Proceedings of an international symposium held at Agadir, Morocco, 16-21 January 1994. 460-463

Serek M, Sisler EC, Reid MS, Nito N (ed.), Looney NE (ed.), Nevins DJ (ed.) and Halevy AH, 1995c. 1 Methylcyclopropene, a novel gaseous inhibitor of ethylene action, improves the life of fruits, cut flowers and potted plants. Plant bioregulators in horticulture - 1994, proceedings of a symposium held at the XXIV International Horticultural Congress, 21 27 Aug. 1994, Kyoto, Japan. *Acta Horticulturae*, No. **394**, 337-345

Serek M, Sisler EC, Tirosh T and Mayak S SO, 1995d. 1 Methylcyclopropene prevents bud, flower, and leaf abscission of Geraldton waxflower. *HortScience*, **30**: 6, 1310

De Stigter H.C.M. 1980. Ethephon effect in cut 'Sonia' roses after pretreatment with silver thiosulfate. *Acta Horticulturae*, **113**, 27–31.

Van Staden J. 1988. Cytokinins and auxins in carnation senescence. Proceedings of an international workshop on postharvest physiology of ornamentals. *Acta Horticulturae*, **261.**

Suttle J.C. and Kende H. 1978. Ethylene and senescence in petals of *Tradescantia Plant Physiology*, **62**, 267–271.

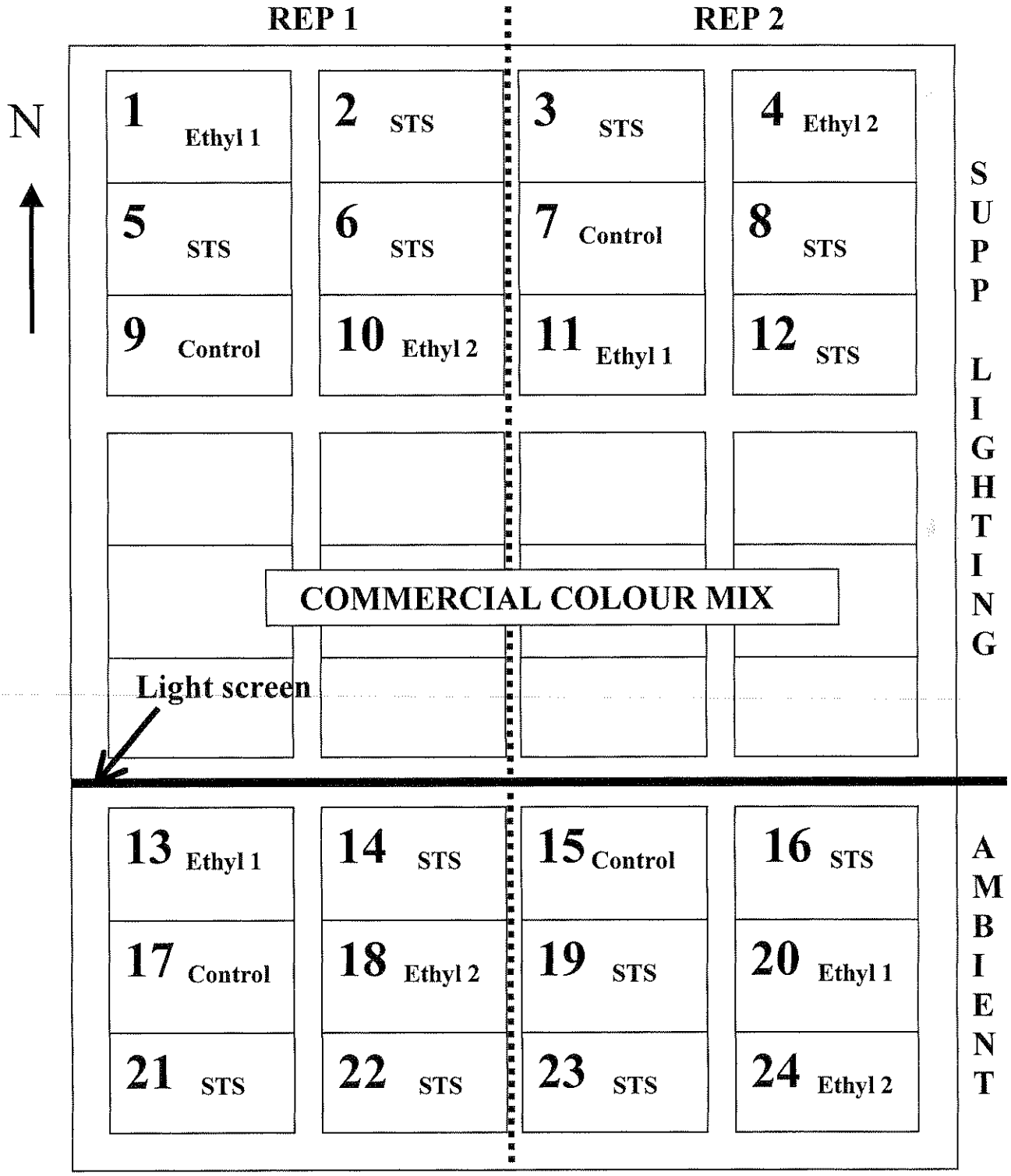
Veen H. and Van de Geijn S.C. 1978. Mobility and ionic forms of silver as related to longevity of cut carnations. *Planta*, **140**, 93–96.

Whitehead C.S., Halevy A.H. and Reid M.S. 1984. Roles of ethylene and 1 aminocyclopropane –1 carboxylic acid in pollination and wound induced senescence of *Petunia hybrida* flowers. *Physiologia Plantarum,* **61**, 643–648.

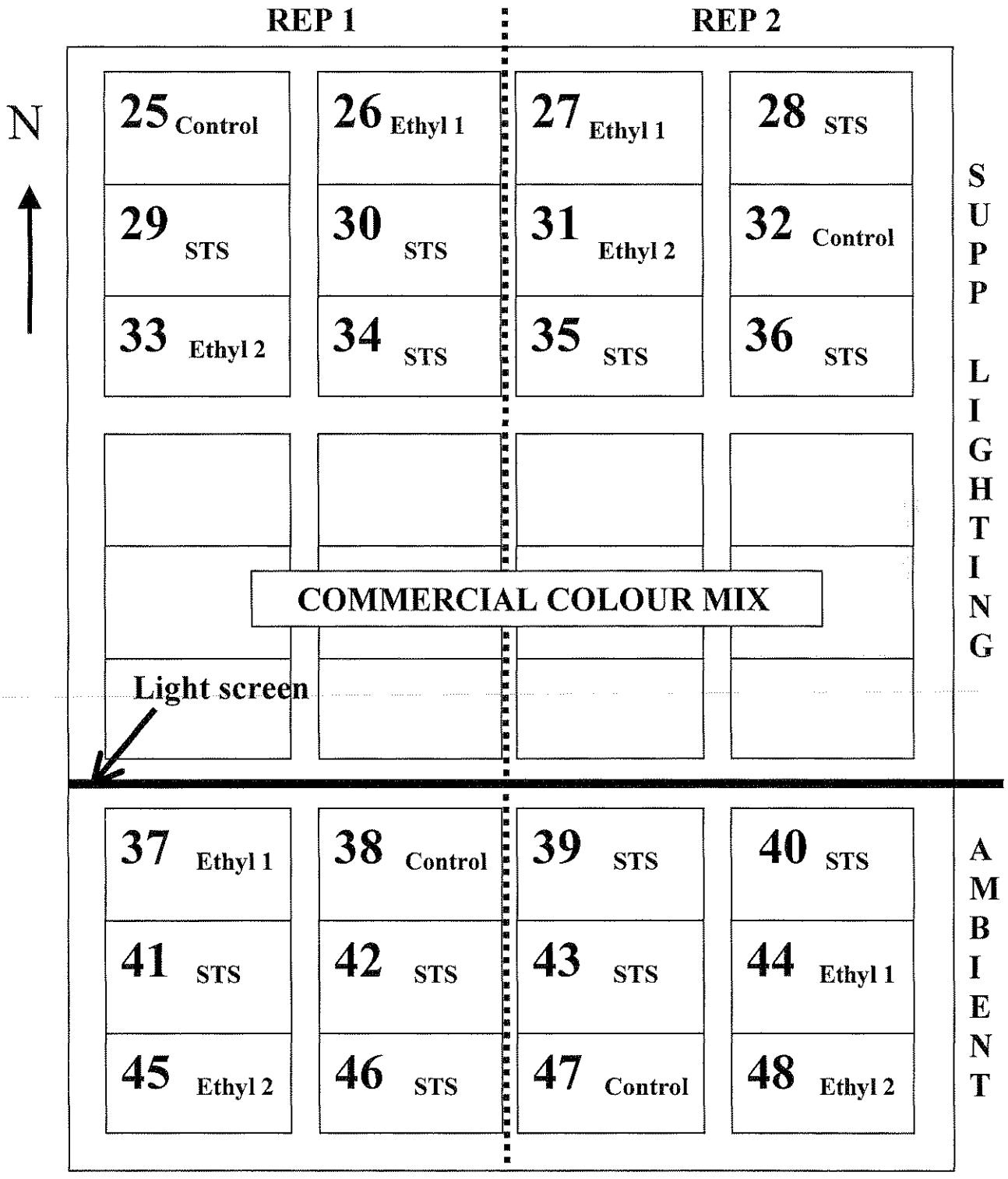
Woltering E.J., 1987. Effects of ethylene on ornamental pot plants: a classification. *Scientia Horticulturae*, **32**, 283-294

Appendices

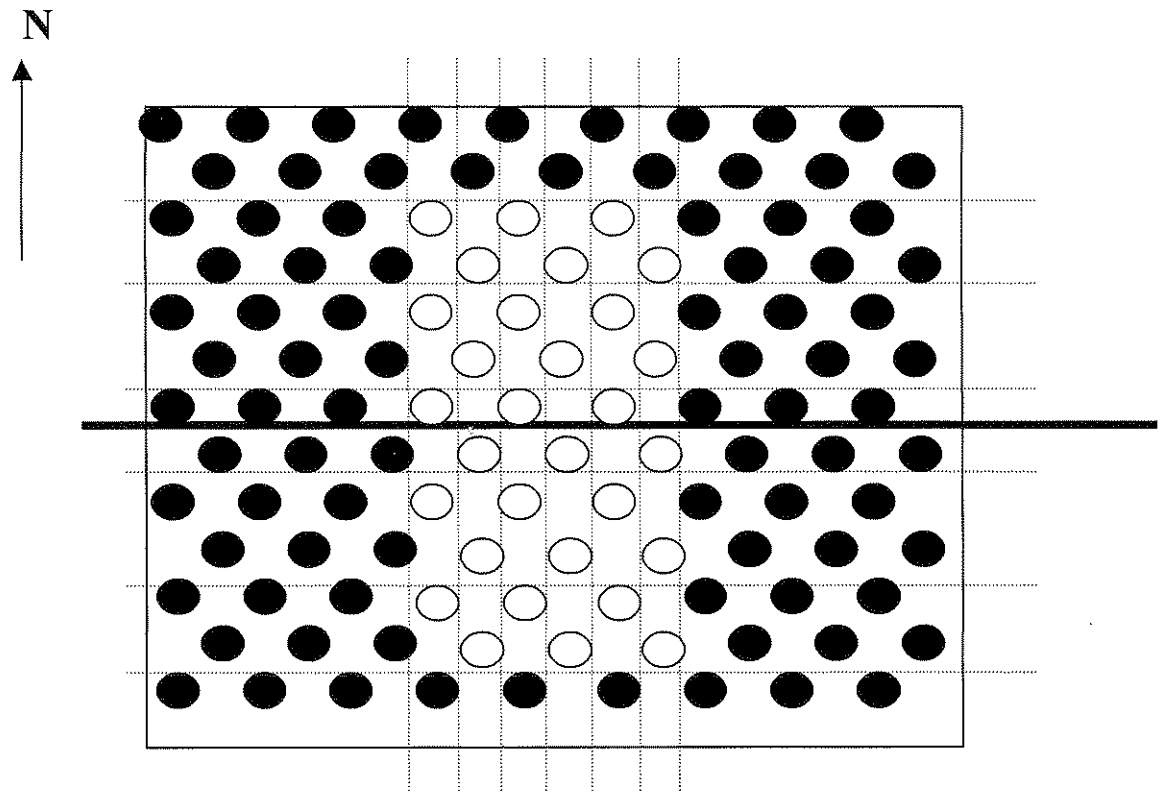
Appendix 1: Treatment layout in Q1 (1000 ppm CO_2)



Appendix 1: Treatment layout in Q2 (350 ppm CO_2)



Appendix 1: Plot plan



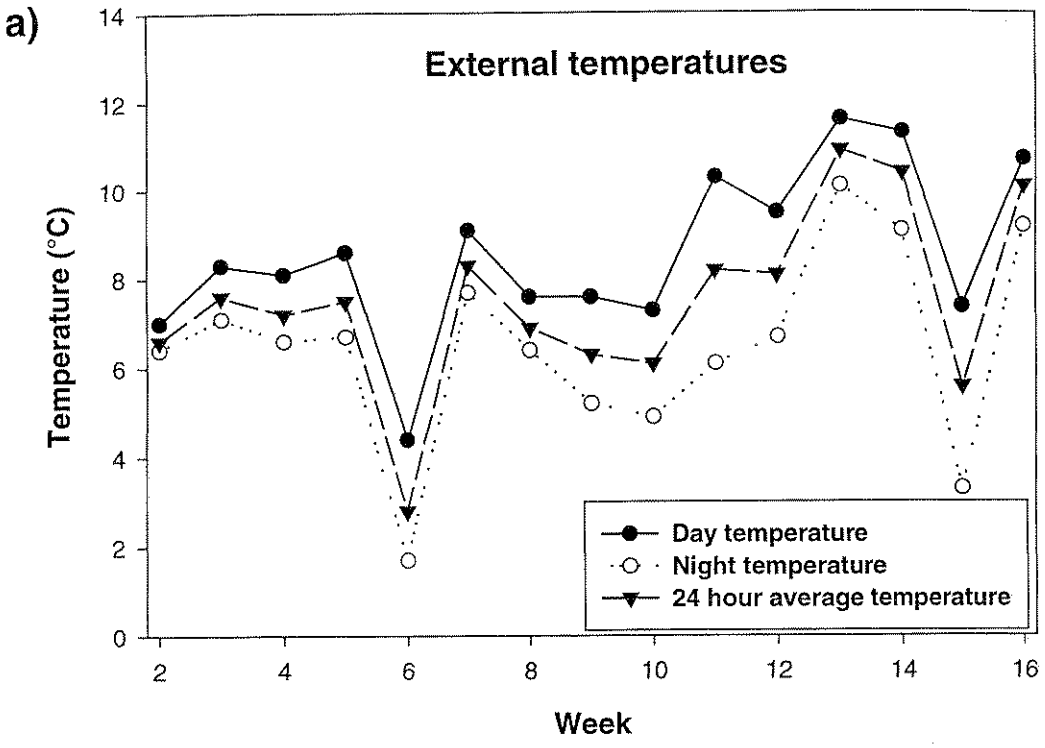
Guard plant

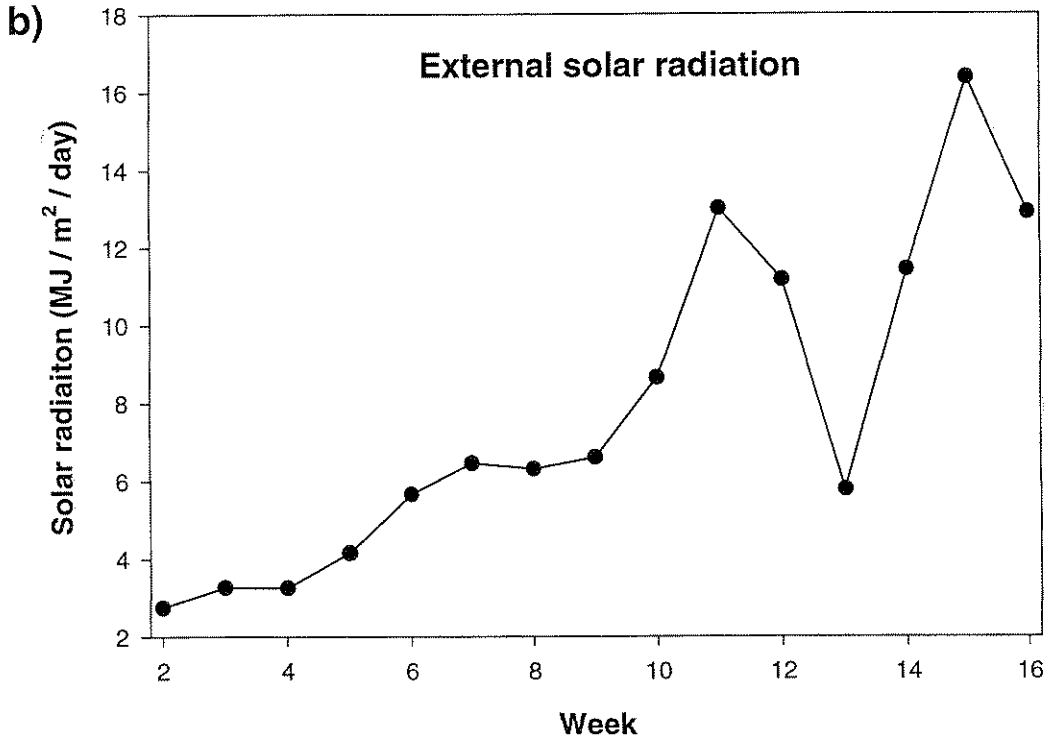
Recorded plant

Appendix 2

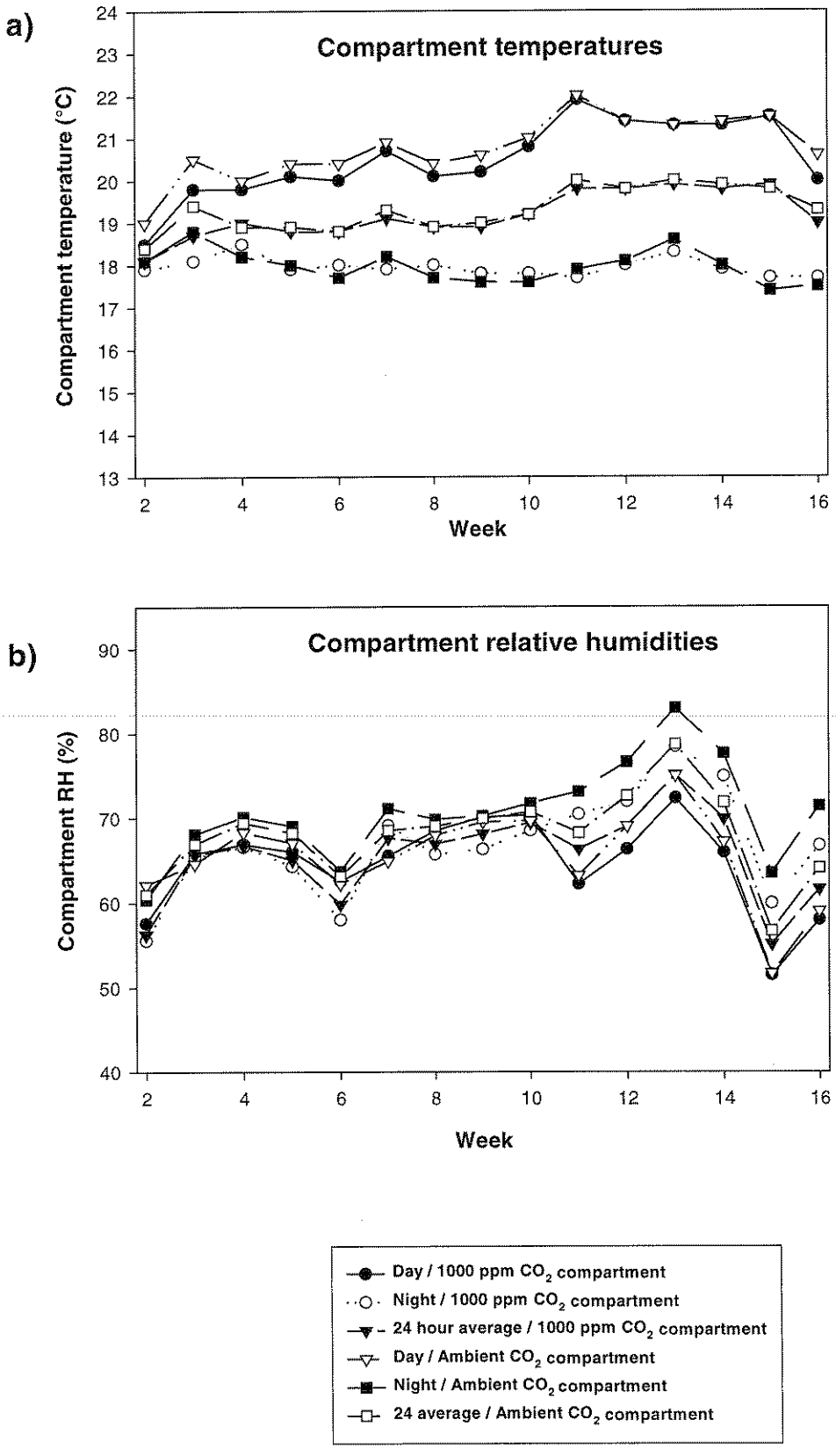
Crop diary : to be inserted

Appendix 3; Figure 1

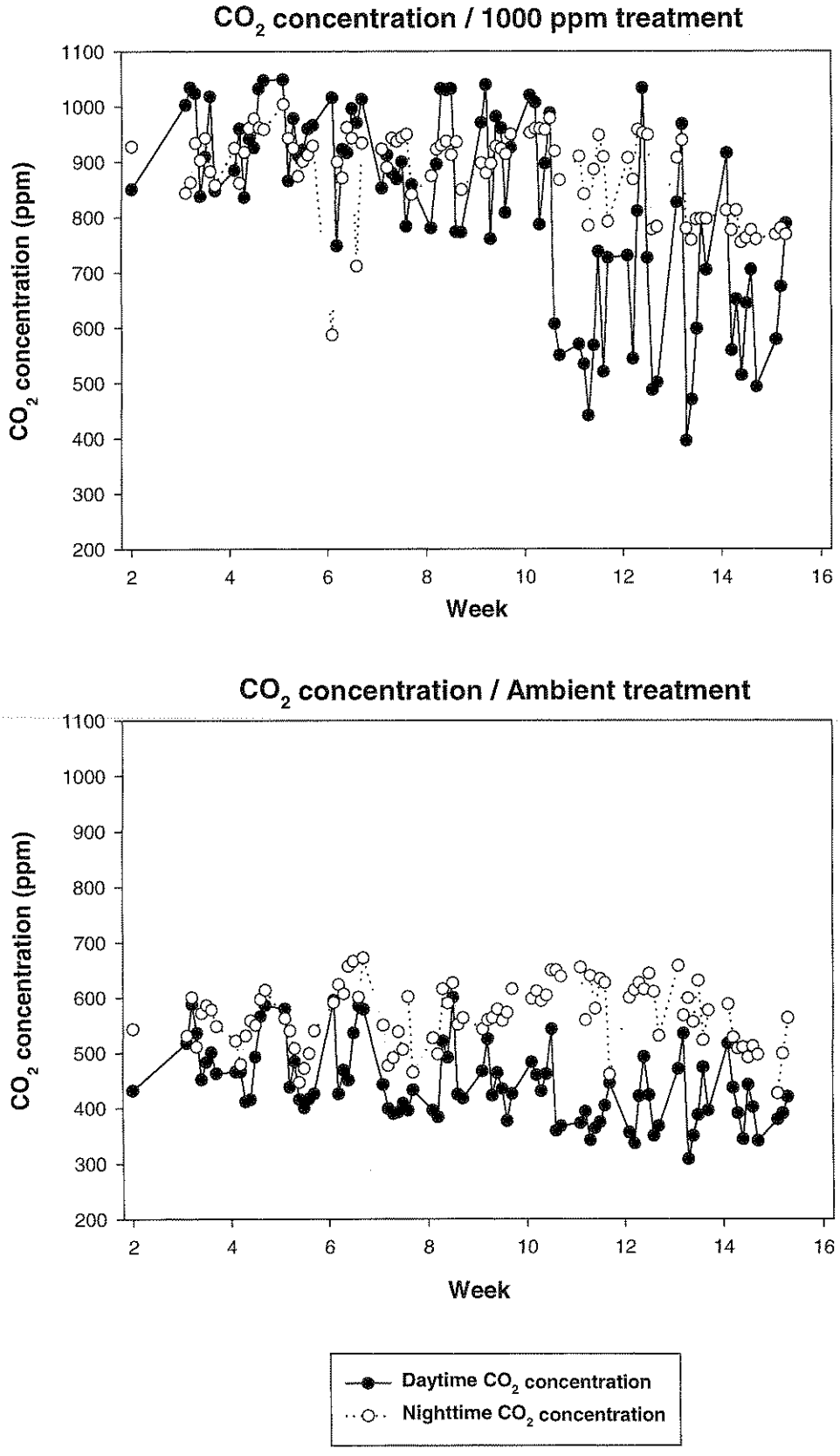




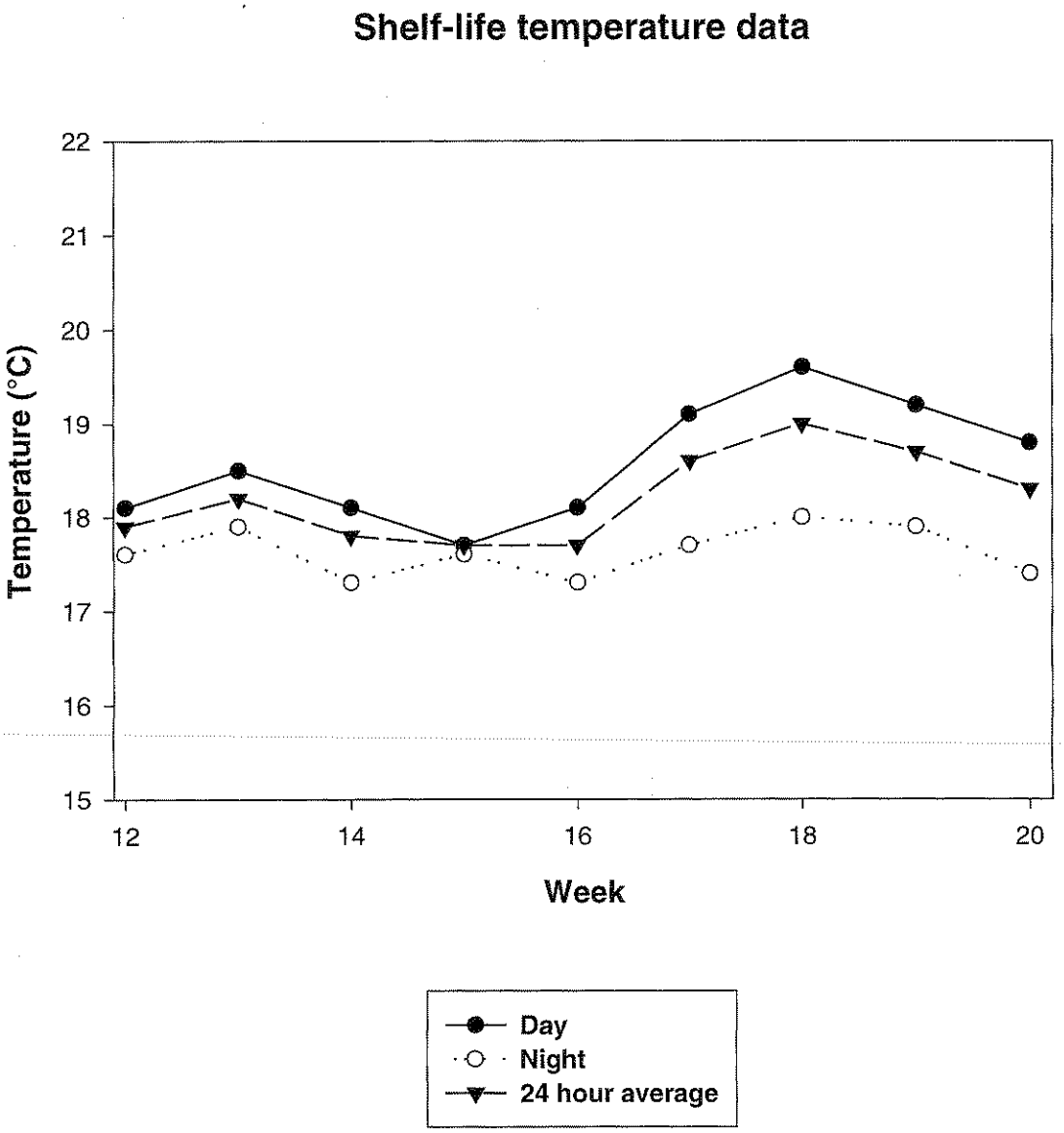
Appendix 3; Figure 2



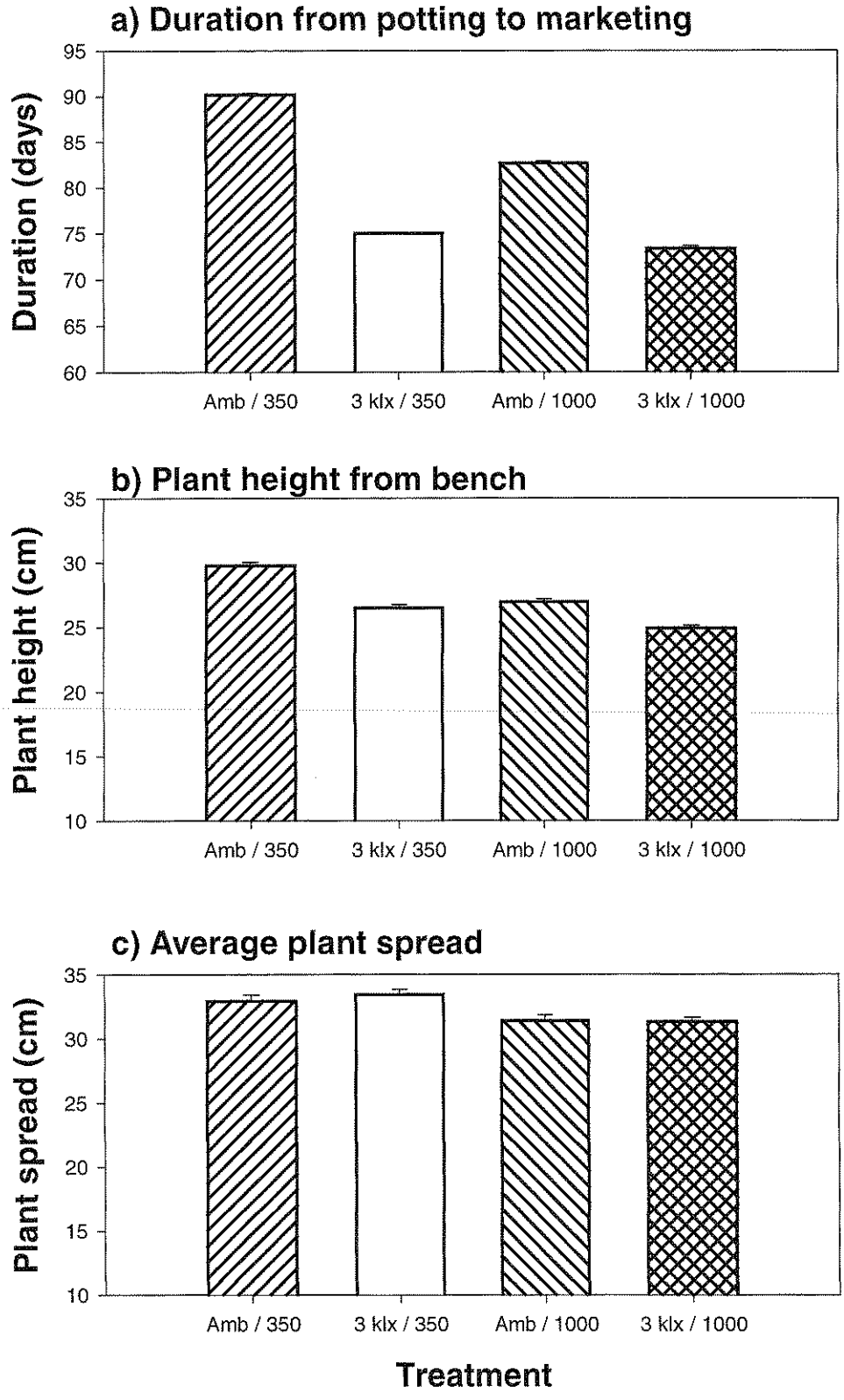
Appendix 3; Figure 3



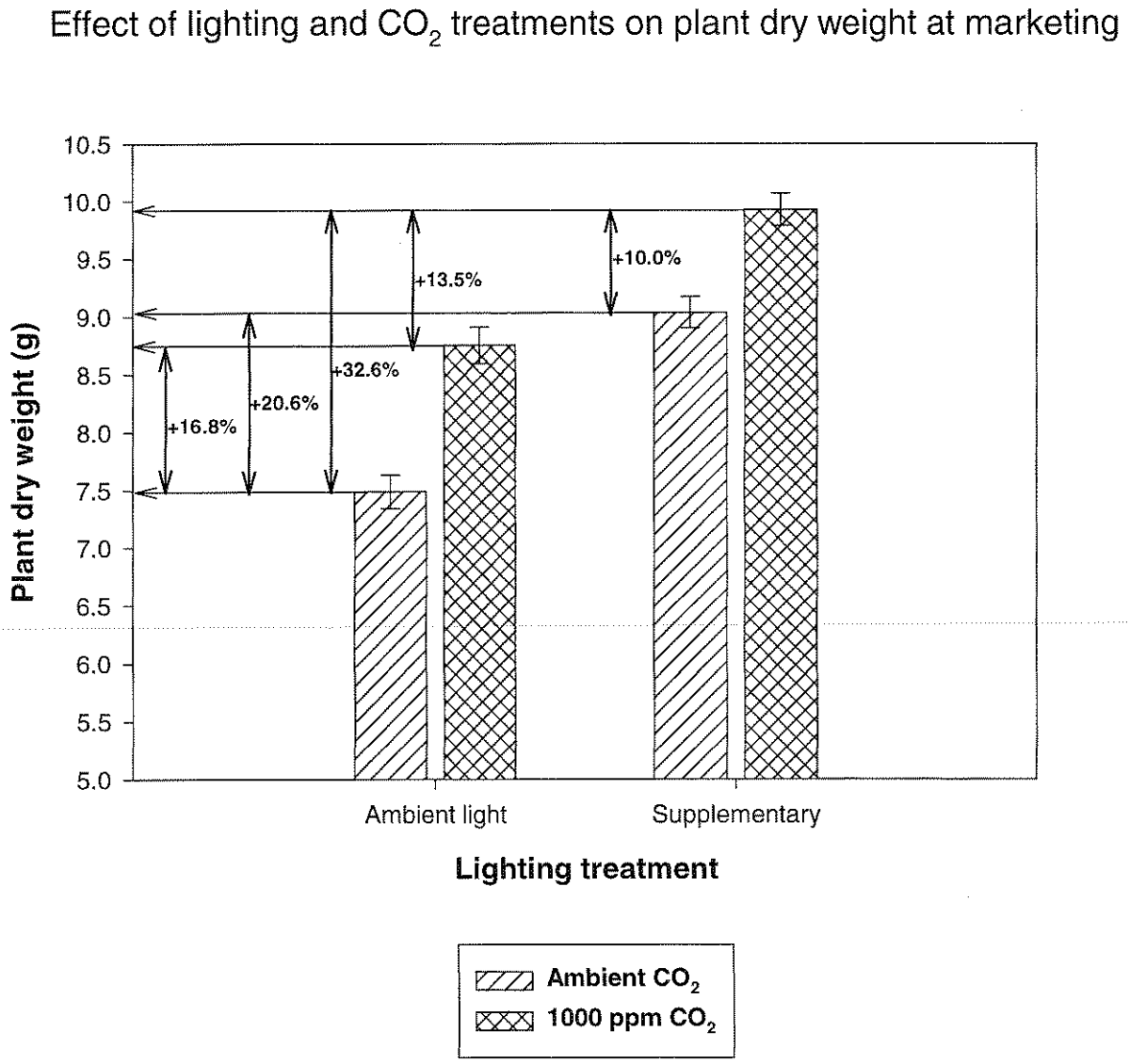
Appendix 3; Figure 4



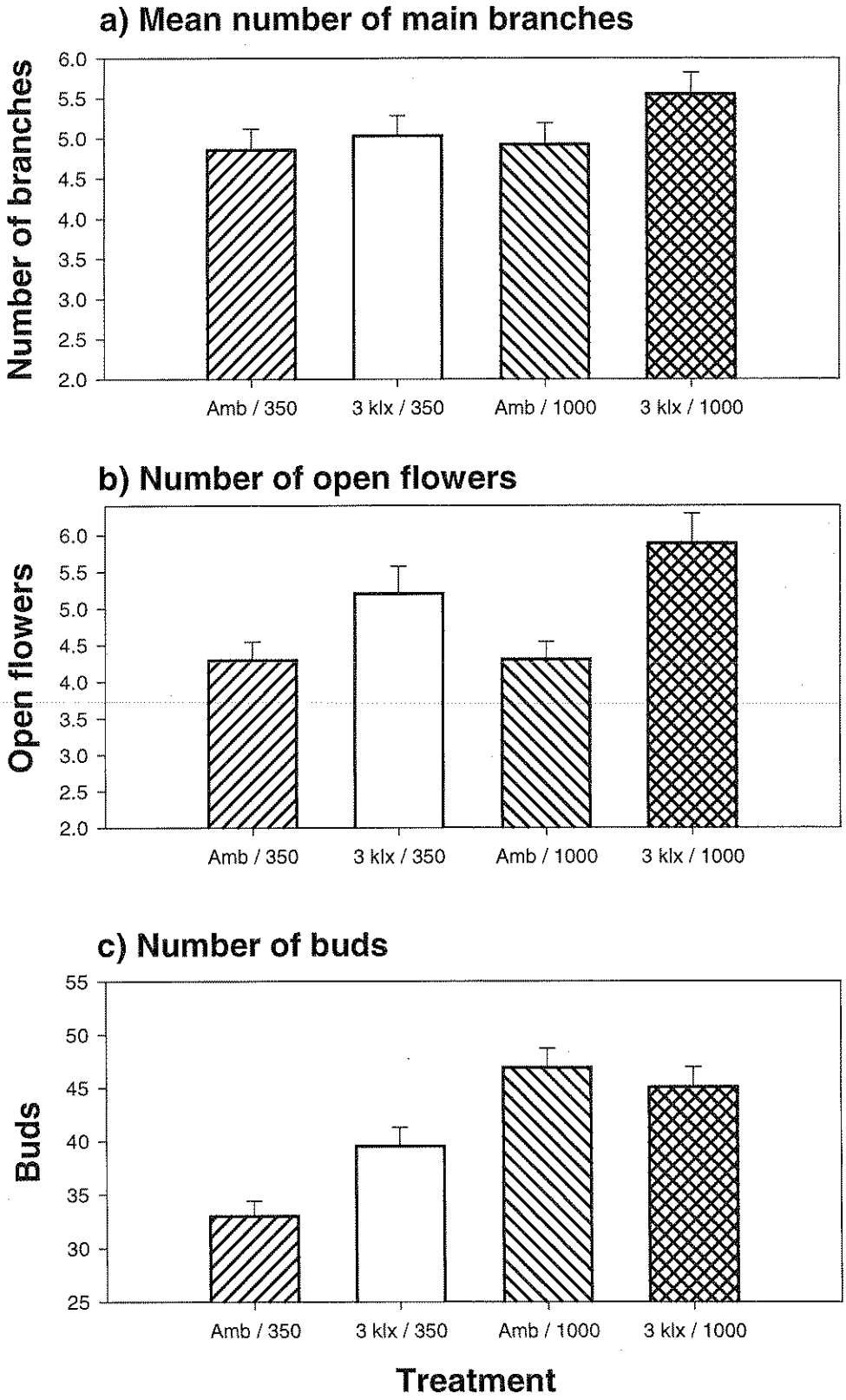
Appendix 4; Figure 1



Appendix 4; Figure 2

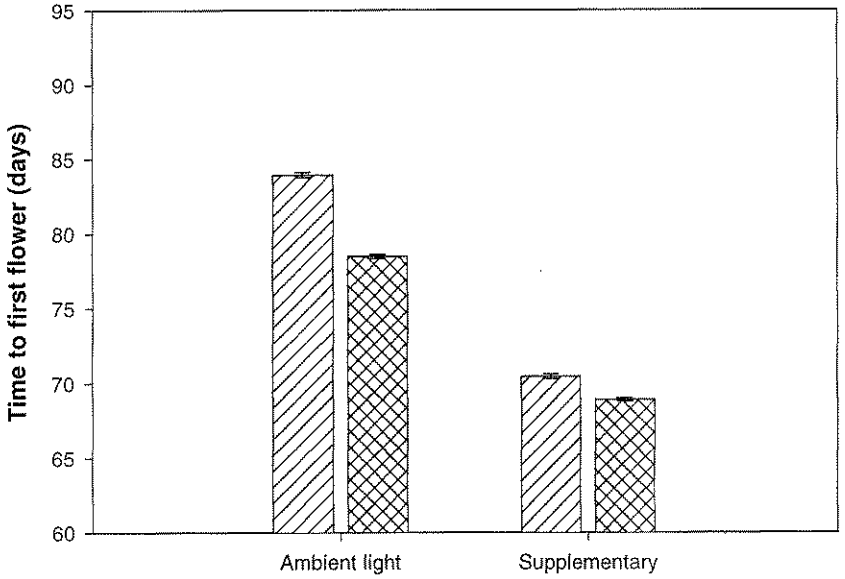


Appendix 4; Figure 3

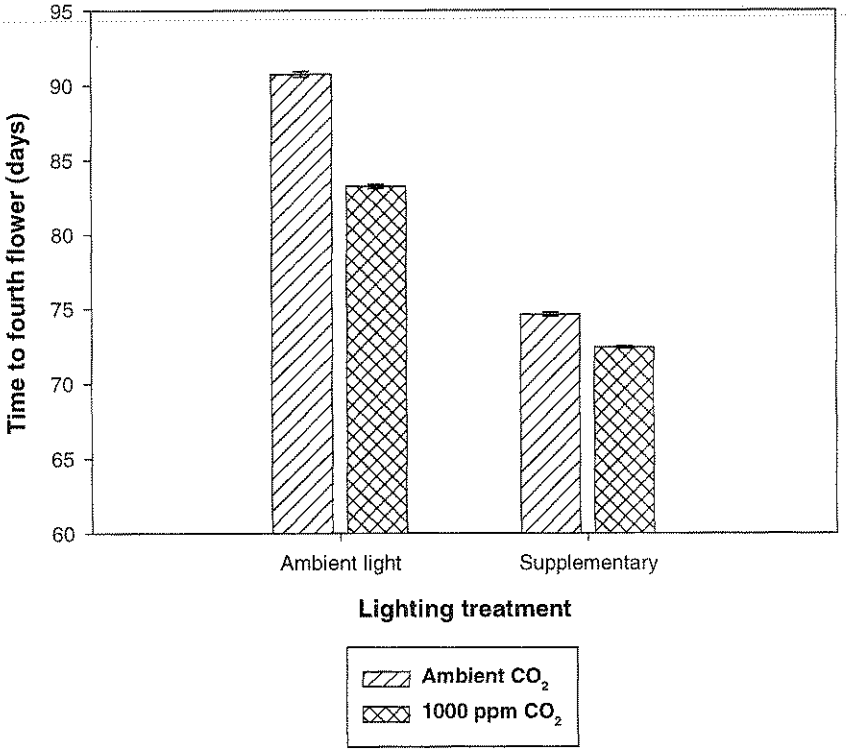


Appendix 4; Figure 4

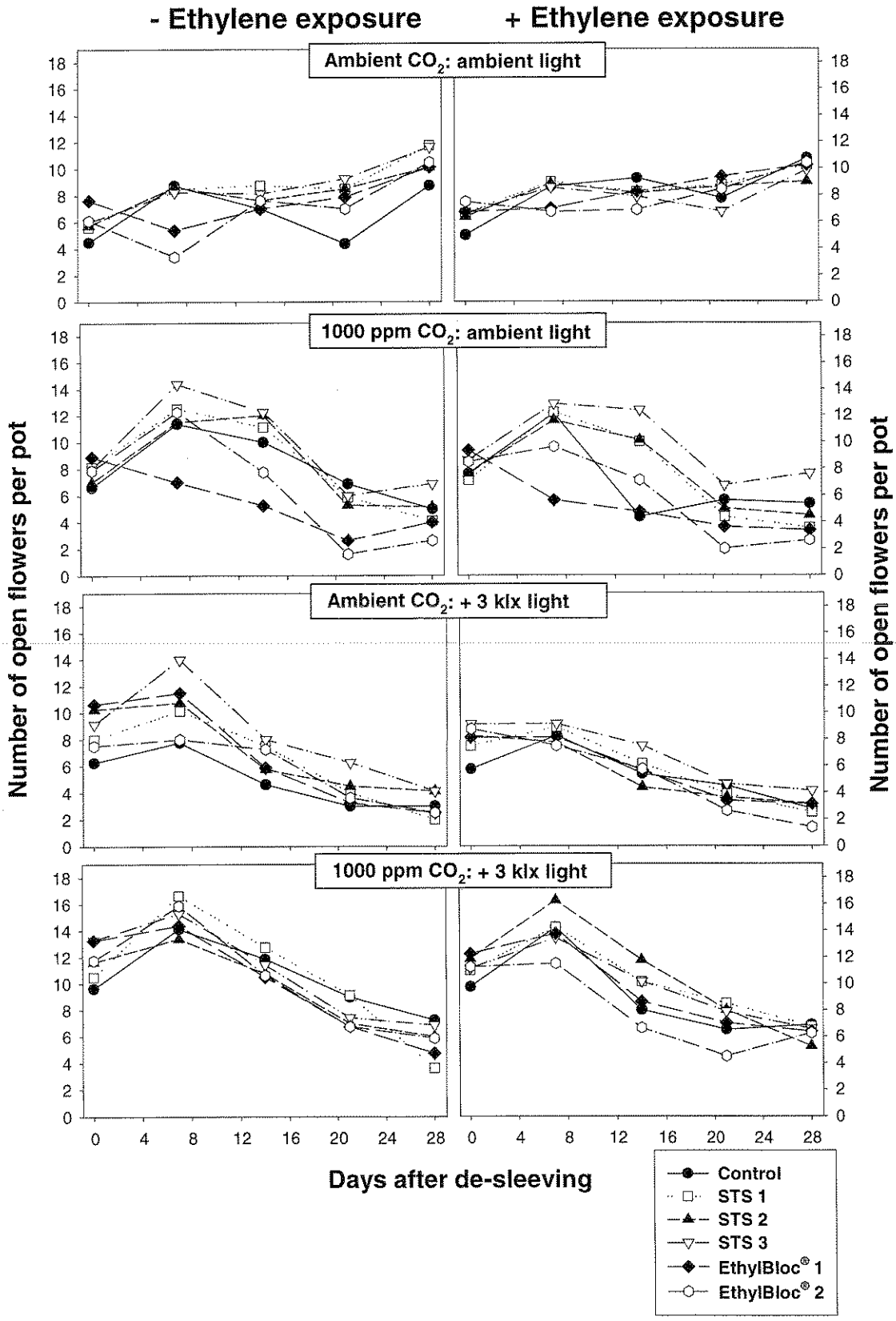
a) Effect of lighting and CO_2 treatments on time to first flower



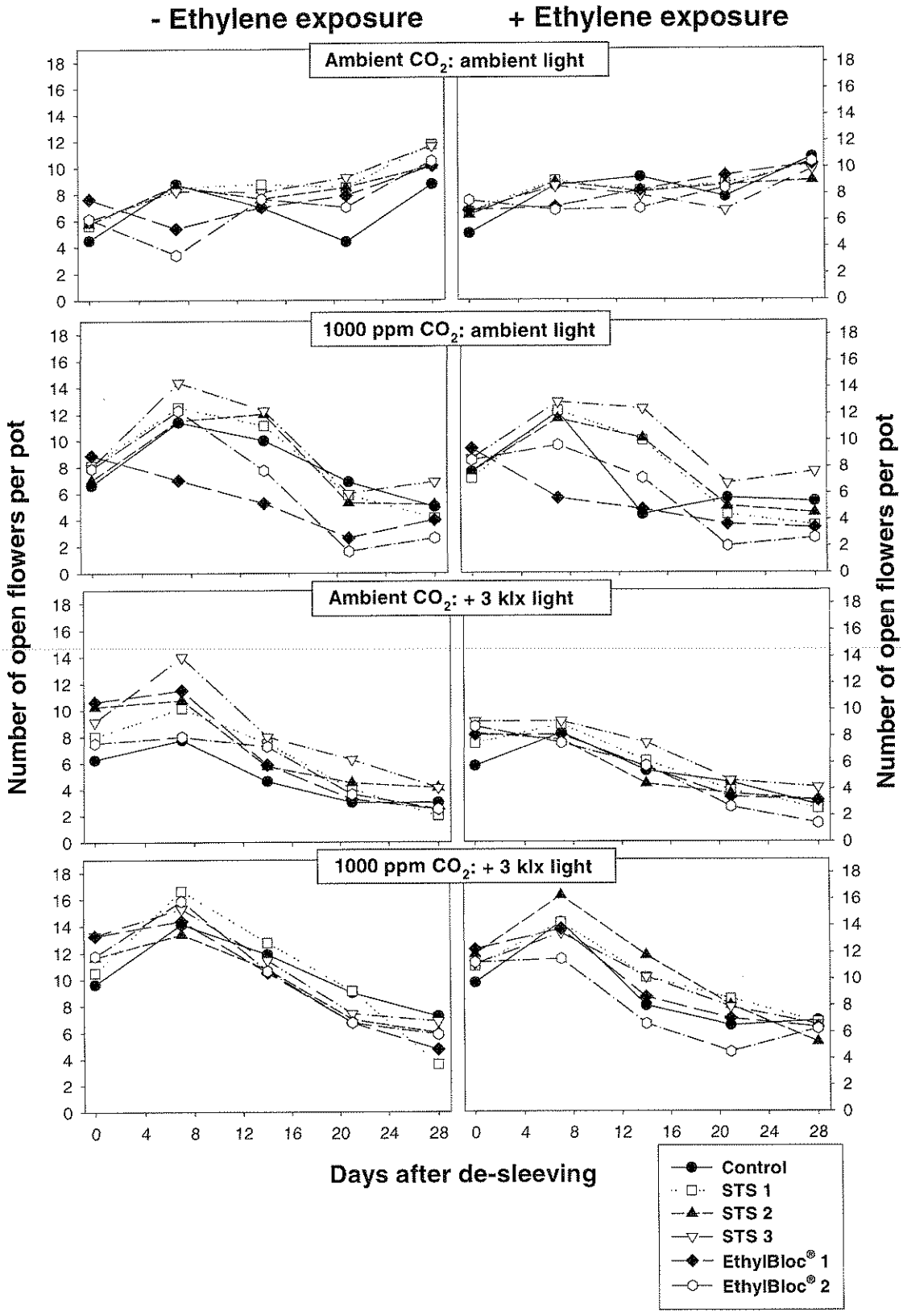
b) Effect of lighting and CO_2 treatments on time to fourth flower



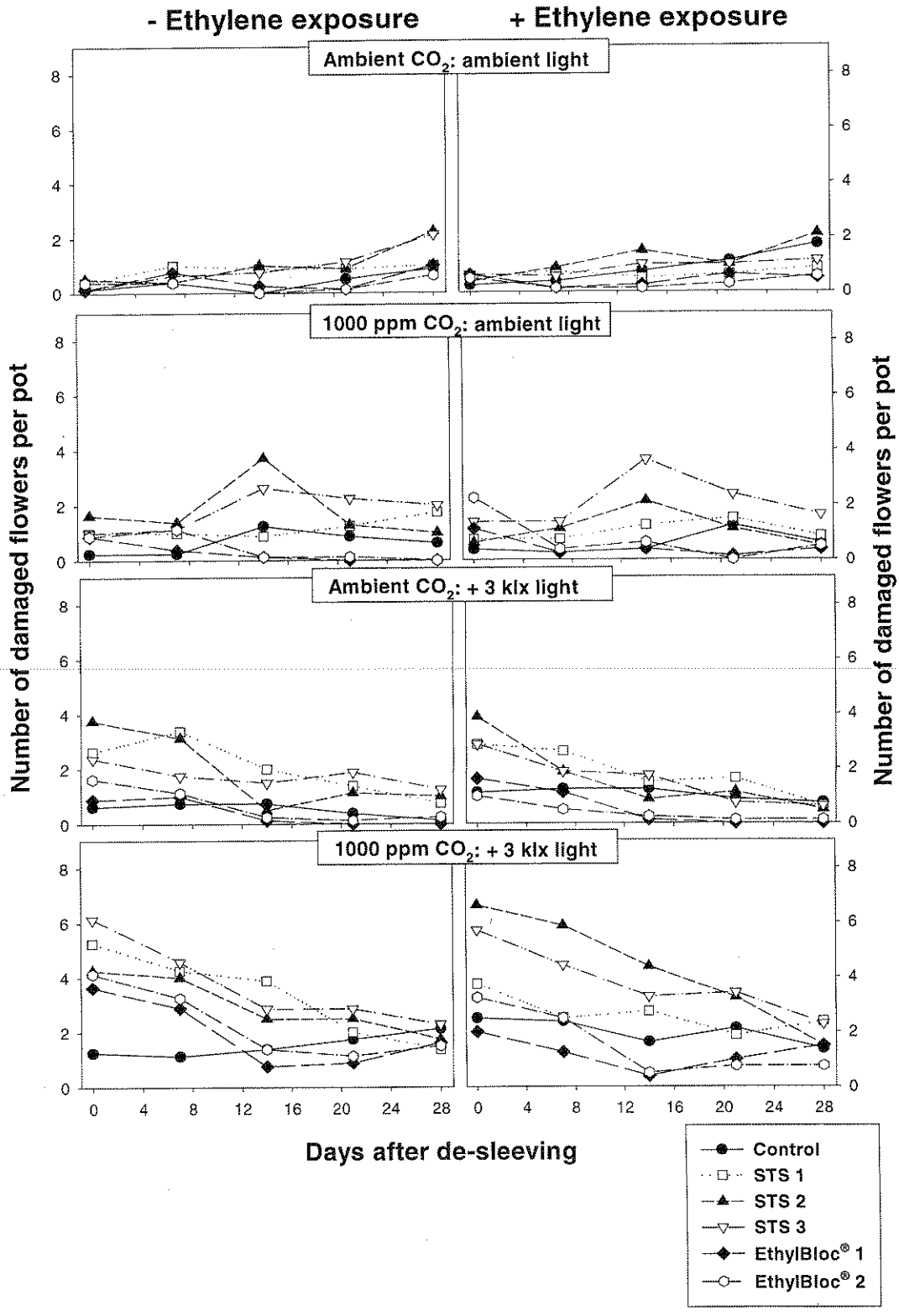
Appendix 5; Figure 1: Production and post-production treatment effects on number of open flowers post-harvest in new guinea impatiens.



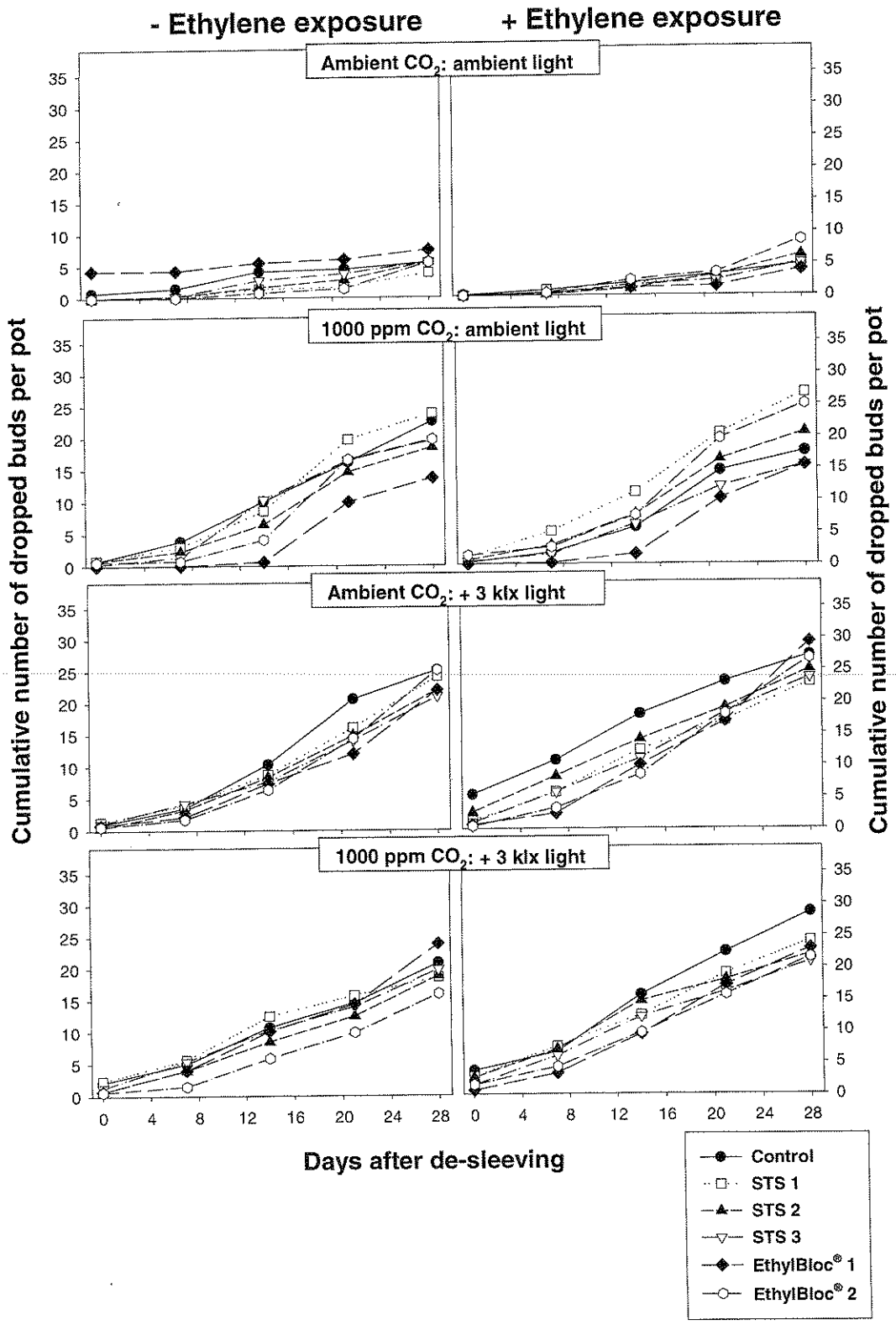
Appendix 5; Figure 2: Production and post-production treatment effects on post-harvest flower loss in new guinea impatiens.



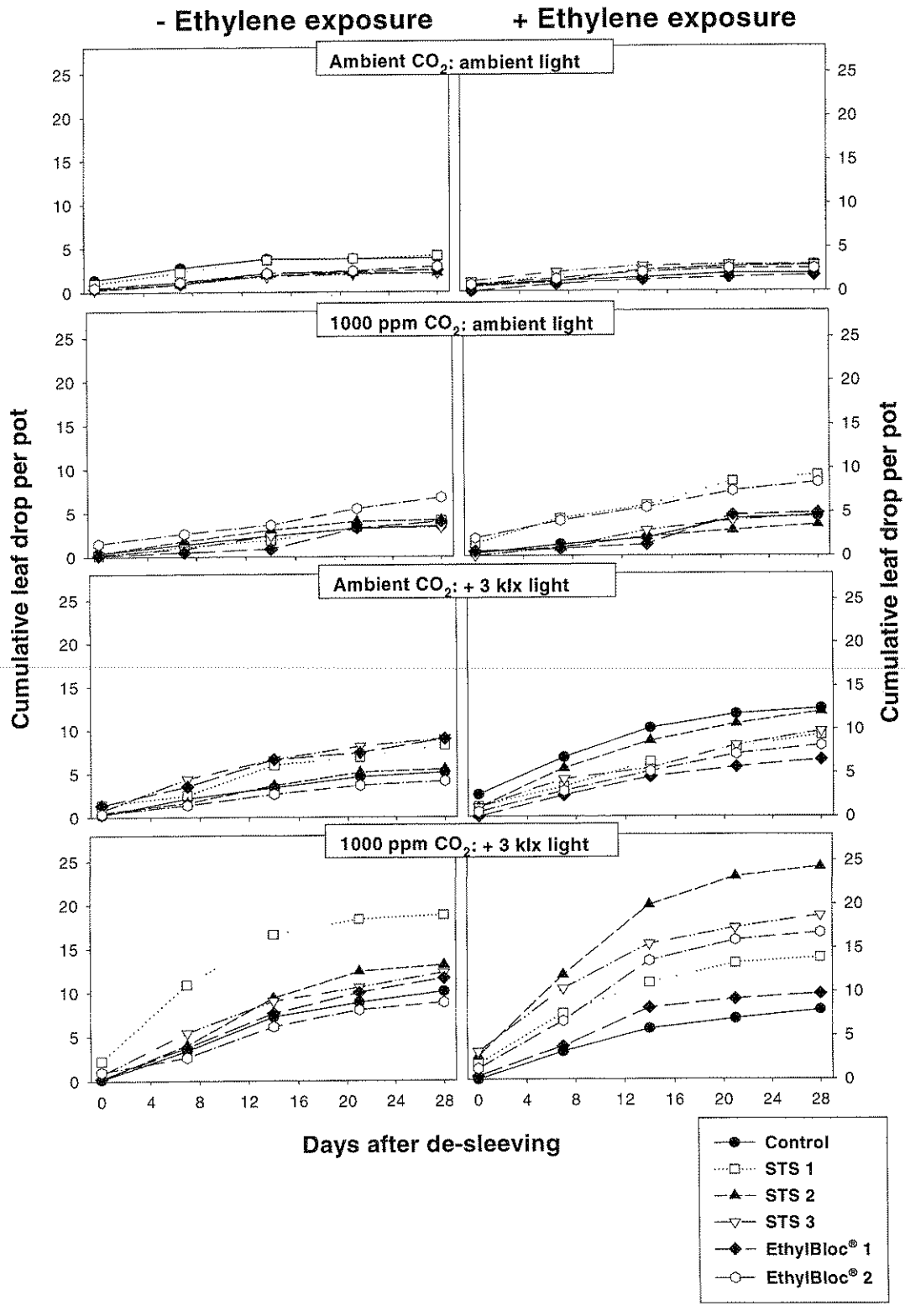
Appendix 5; Figure 3: Production and post-production treatment effects on post-harvest flower damage in new guinea impatiens.



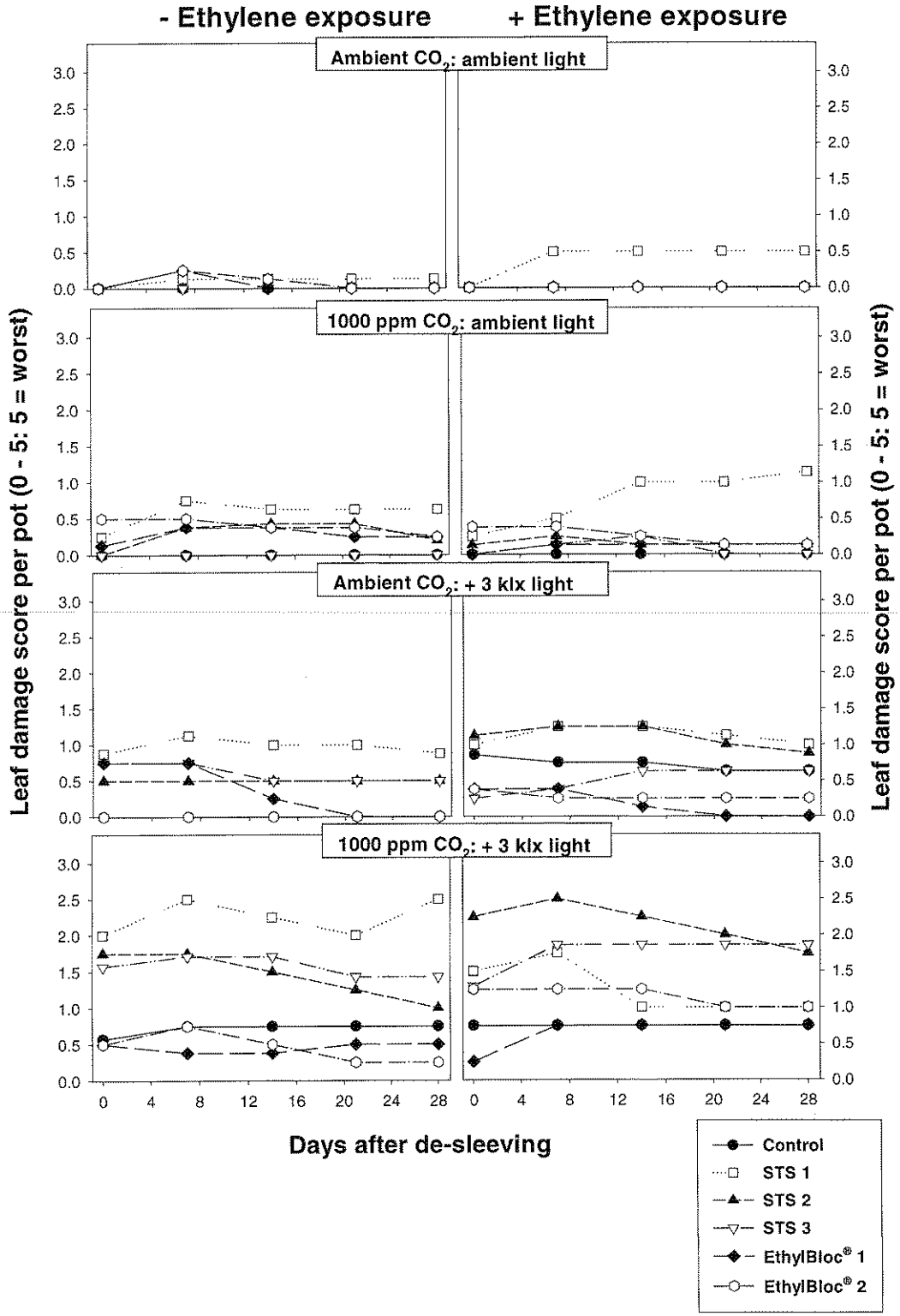
Appendix 5; Figure 4: Production and post-production treatment effects on post-harvest bud loss in new guinea impatiens.



Appendix 5; Figure 5: Production and post-production treatment effects on post-harvest leaf loss in new guinea impatiens.



Appendix 5; Figure 6: Production and post-production treatment effects on post-harvest leaf damage in new guinea impatiens.



Appendix 6: MEDIA ANALYSIS DATA

Ambient CO_2	BD	pH	EC	NO3 as N	NH4 as N	K	Ca	Mg	P	Fe	Zn	Mn	Cu	B	Na	S
Ambient Light	(g/ml)				(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Week																
2	0.195	6.3	287	84	0.5	168	57	36	60	0.83	0.86	0.16	0.14	0.44	60	44
6	0.264	6.2	245	82	0.4	112	73	47	34	0	0.56	0.14	0.05	0.15	36	22
9	0.264	6.0	307	94	1.2	118	172	94	42	0	6.94	0.41	0.35	0.08	42	161
11	0.235	6.1	154	36	1.6	60	56	30	30	0	2.59	0.01	0.28	0.11	90	25

Ambient CO_2 Supp light	BD (g/ml)	pH	EC	NO3 as N (mg/l)	NH4 as N (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	P (mg/l)	Fe (mg/l)	Zn (mg/l)	Mn (mg/l)	Cu (mg/l)	B (mg/l)	Na (mg/l)	S (mg/l)
Week																
2	0.195	6.3	287	84	0.5	168	57	36	60	0.83	0.86	0.16	0.14	0.44	60	44
6	0.277	6.1	245	88	0.2	120	79	46	35	0	0.52	0.15	0.04	0.13	60	26
9	0.377	6.4	242	63	1.1	108	92	46	35	0	2.03	0.14	0.29	0	84	93
11	0.211	6.5	114	6	1.2	36	38	19	23	0	2.85	0.02	0.29	0.01	66	25

1000 ppm CO_2 Ambient Light	BD (g/ml)	PH	EC	NO3 as N (mg/l)	NH4 as N (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	P (mg/l)	Fe (mg/l)	Zn (mg/l)	Mn (mg/l)	Cu (mg/l)	B (mg/l)	Na (mg/l)	S (mg/l)
Week																
2	0.195	6.3	287	84	0.5	168	57	36	60	0.83	0.86	0.16	0.14	0.44	60	44
6	0.23	6.4	132	46	1.8	74	41	22	20	0	0.31	0.07	0.03	0.24	30	15
9	0.237	5.6	210	94	1.5	109	74	40	30	0	1.08	0.02	0.33	0.08	42	22
11	0.233	6.2	132	14	1	38	49	24	33	0	1.9	0	0.07	0.37	72	31

1000 ppm CO_2 Supp light	BD (g.ml)	pH	EC	NO3 as N (mg/l)	NH4 as N (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	P (mg/l)	Fe (mg/l)	Zn (mg/l)	Mn (mg/l)	Cu (mg/l)	B (mg/l)	Na (mg/l)	S (mg/l)
Week																
2	0.195	6.3	287	84	0.5	168	57	36	60	0.83	0.86	0.16	0.14	0.44	60	44
6	0.246	6	194	89	0.5	130	83	55	43	0.14	0.7	0.19	0.07	0.21	54	34
9	0.308	6.4	90	6	1.1	23	26	8	19	0	1.11	0.17	0.32	0.01	72	66
11	0.216	6.1	79	3	1.3	19	32	14	21	0	2.28	0.01	0.15	0.15	48	14

Appendix 7

Modelling component of HDC NGI work

(Dr Simon Pearson, University of Reading)

Modelling Component of HDC New Guinea Impatiens Work.

Prior to this HDC funded work a large MAFF program was conducted in which a mechanistic model was constructed in order to simulate the effects of temperature and light on the growth and flowering of new guinea impatiens. This model has been designed as a tool to aid plant scheduling. It can forecast rates of plant growth and flowering dates for new guineas potted at a range of dates through-out the season and grown at any temperature with or without supplementary lighting.

This model was partially validated in that study, but the effects of carbon dioxide on new guinea growth were not fully modelled. The aims of the work here were to further validate the model, incorporate effects of carbon dioxide in the model and to use it to provide potting date schedules for new guineas grown under a range of commercial regimes.

The model is constructed in a LOTUS-123 spreadsheet. It determines the rate of canopy photosynthesis in response to light and temperature, and then allows for carbon losses via respiration processes. The remaining carbon fixed is then converted into either leaf, stem or flower dry matter components, with rates of these processes being temperature driven. Flowering only starts after the process is triggered within the model, i.e. after a set amount of developmental time has progressed which is temperature dependent. Flowering is then a function of the amount of free assimilates available within the plant, if the plant is growing rapidly and plenty of carbon is available then rate of flowering (number of flowers which appears) increases, and vice versa.

The initial step in this project was to make the model carbon dioxide dependent. This was simply achieved by assuming that rate of canopy photosynthesis. This used standard equations developed for a range of crops which may grow in enriched carbon dioxide concentrations (Pachepaksy and Acock, 1997). It was assumed that no acclimation of photosynthesis to carbon dioxide enrichment occurred. The environmental data collected at Efford was then run through the model in order to predict flowering dates (when four open flowers appeared) and dry mass at harvest. All parameter values within the model were as described in the original MAFF report, however, these were developed for the variety Delias, which was not used within the Efford trial. One of the most important values within the model is the initial plant dry weight at potting, since this determines how quickly the plant establishes and grows. This value was assumed to be within the range measured during the earlier MAFF trials.

Figures ****a and ****b show the results of the validation of the model, in terms of its ability to forecast plant dry weight and flowering dates. In terms of final dry weight the model systematically underestimated dry weight at flowering, by

approximately 1g per plant. This is not surprising since a different variety was used at Efford to that studied originally and starting values were estimated, not measured. Given that the error is systematic the model gives a reasonable description of the data. In terms of days to marketing the original MAFF model (open symbols on the graph) predicted marketing date to within +/- 7 days. This was considered unacceptable and may be that the Efford crop was potted earlier (week 5) than any of the MAFF crops used in model validation. Consequently, the model was adapted to account for darker growing conditions and this gave predictions to within +/- 3 to 5 days. This is sufficiently accurate to develop schedules for the production of crops to within any particular week.

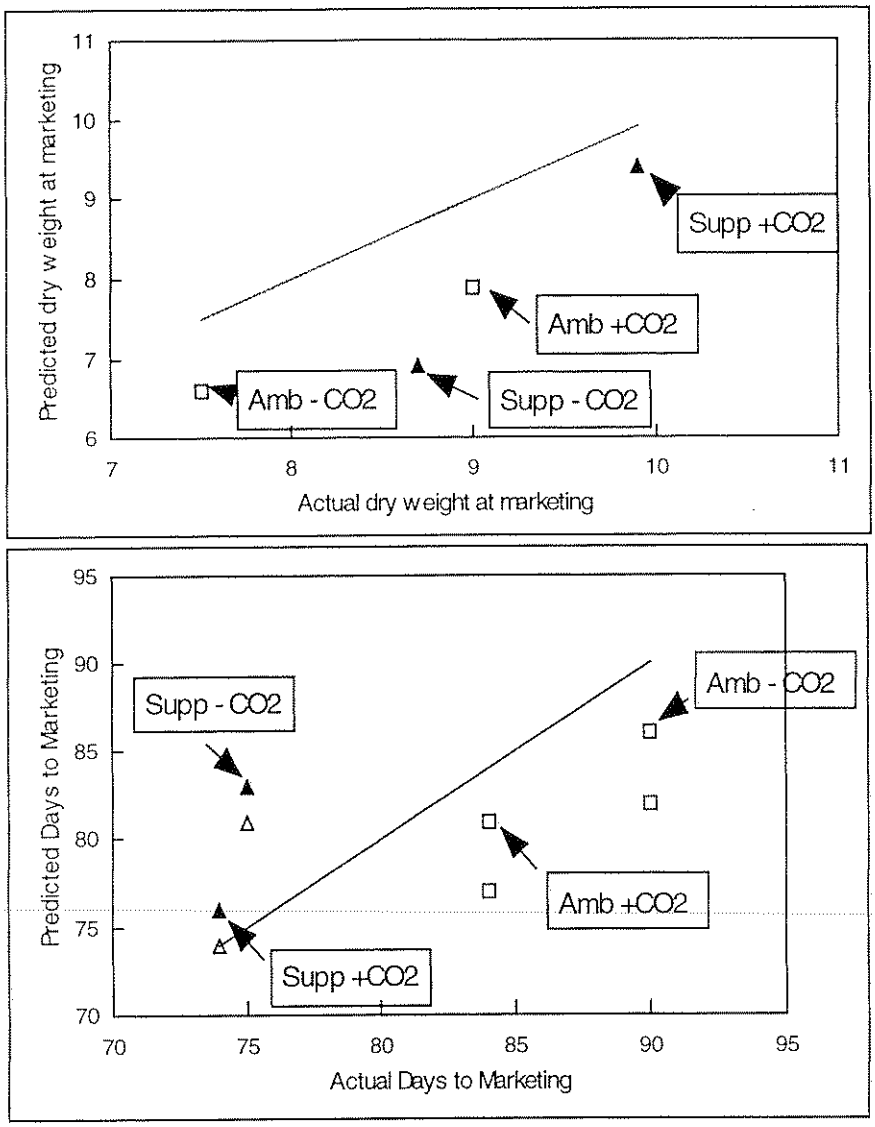


Figure xxxx a and xxxxb. Predicted versus actual dry weights (upper graph) and flowering dates (lower graph). Square symbols were plants grown in ambient light levels and triangles were plants given supplementary radiation at the rate used at Efford. On the lower graph the open symbols represent the model simulation as calibrated within the MAFF project, the closed symbols are with the new adapted model.

The model was then used to develop a range of production schedules for New Guinea Impatiens grown with or without supplementary light or carbon dioxide (Figures *** and ***).

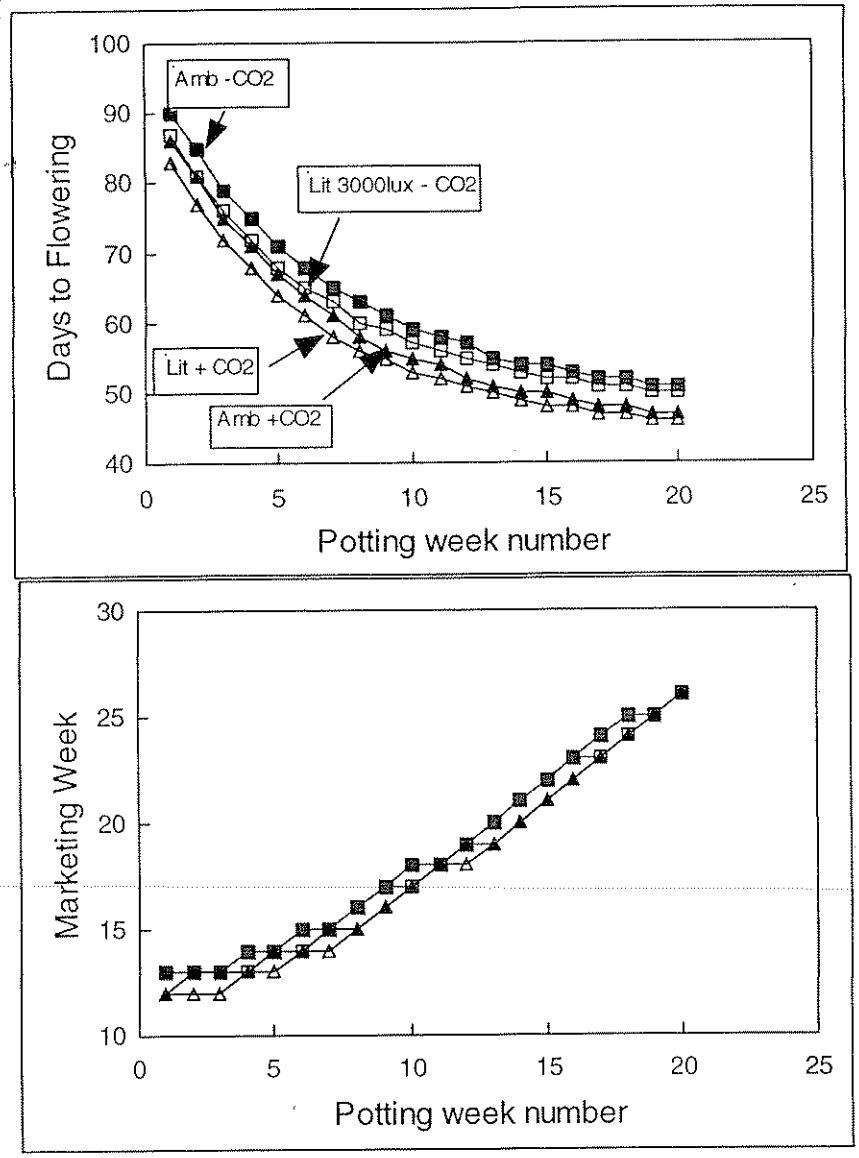


Figure **** and ****. The upper graph shows the days to marketing of new guinea impatiens potted on a range of dates and grown at a temperature of 19°C but with (or without supplementary light (2500lux) or carbon dioxide (set 1000ppm); symbols are shown on the graph. The lower graph shows a potting date schedule for new guinea impatiens, symbols are the same as the upper graph but removed for clarity.

The current commercial practice is similar to the ambient – CO^2 treatment. The simulations show that the use of supplementary light and carbon dioxide enrichment will reduce the time to marketing by about 7 to 10 days. The lower graph demonstrates a potting date schedule for new guinea impatiens. Once marketing dates are selected the grower can read off the graph when it should be potted.

The main caveat to this schedule is that it was developed using 'average' weather and light conditions for Reading. Weather is never average and therefore this schedule should be used as a guide only and may also need adapting according to local production techniques.