HORTICULTURE RESEARCH INTERNATIONAL

EFFORD

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CONTRACT REPORT

Chrysanthemums: Hydroponic systems for AYR chrysanthemums

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Chrysanthemums: Hydroponic systems for AYR Chrysanthemums

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

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CONTENTS

RELEVANCE TO GROWERS AND PRACTICAL APPLICATION

Application

Successful production of AYR chrysanthemums was achieved on substrate-based (sand and Probase) hydroponic systems during both the winter and spring trial period, 1991/92. Hydroponic crops outperformed the soil grown crops on both occasions.

The potential therefore exists for manipulation of crop growth to improve productivity. If these systems can be developed to minimize disease risk with minimal sterilization and cultivation requirements then hydroponic production of chrysanthemums will become increasingly attractive and cost effective.

Summary

It is recognised that there is potential for improvements in plant quality from growing AYR chrysanthemums in hydroponic systems. This, coupled with concern about emission of chemicals into the sub-soil, resulted in HDC funding the study of a range of closed systems for soil-less production at HRI Efford.

A range of hydroponic systems was compared:

1.	Aeroponic	-	root moistening system
2.	Hydroponic system	-	Probase base
3.	Hydroponic system	-	sand base
4.	Soil	-	conventional system

Three plantings were examined:

I	Spring 1991	-	*Snowdon, Delta*
II	Winter 1991	-	*Snowdon, Delta*
III	Spring 1992	-	*Delta, White Fresco*

Plant growth was assessed at stages in the crop schedule. Weekly analysis of nutrient solution, disease assessment of roots at key developmental stages, duration of cropping, height, grade out at marketing and shelf-life were recorded.

Successful production of AYR chrysanthemums was achieved on hydroponic systems during both the winter and spring trial period. Hydroponically grown crops outperformed the soil grown crops on both occasions. Plants grown on the hydroponic systems, sand and Probase, were of better quality. They were taller with thicker stems and larger leaves than the conventionally soil grown crop.

Plants in the aeroponic system proved difficult to establish, especially when propagated in jute plugs. Comparison of frequency of misting in Planting III demonstrated an improvement in growth from more frequent irrigation pulses ('English' system as compared with 'Dutch' system). However, even with increased frequency of irrigation, plant quality in the aeroponic system was still less than that achieved in the soil or hydroponic system.

Action Points

It is recommended that future work should address the following critical areas:

- Effect on crop establishment and productivity of plant pathogenic organisms present in the substrate
- Implications for disease spread in closed systems
- Influence of Aaterra on plant performance
- Influence of low pH of recirculating solution on plant quality and disease suppression
- Depth of sand in hydroponic culture

EXPERIMENTAL SECTION

INTRODUCTION

Unlike protected edible crops AYR chrysanthemums are conventionally grown in glasshouse soil. In the last 15-20 years, European research workers have made numerous attempts to grow chrysanthemums without soil, but because the systems were too costly or posed problems of root disease, they were not taken up and developed by the industry. However, recent concern about crop productivity and increased international competition, coupled with concern about emission of nutrients into the sub-soil and ground water, has revived this interest and stimulated new research and development of closed systems for soil-less production of AYR chrysanthemums.

Soil-less cultivation can take place in a range of systems. These include aeroponic or root misting systems and use of nutrient film technique (NFT) as well as substrate based hydroponic systems.

Hydroponic systems rely on use of a solid medium to support the roots. These have ranged from mixtures of glasshouse soil and perlite to coconut matting, expanded clay granules, sand and silica based waste products. In these systems nutrient solution from a main feed tank is supplied to the bed by drip irrigation. The excess solution drains back to the main feed tank through a central drainage channel. The nutrient solution is continually monitored (using electronic sensing and dosing equipment) and automatically adjusted with stock solutions to achieve pH and conductivity targets. Alternative soil-less systems have included substrate based ebb and flood tanks or non-substrate based NFT and aeroponic systems. In the aeroponic system, roots are suspended through holes in the lid of a trough and sprayed at regular intervals with nutrient solution. Excess solution drains back to the main feed tank and is recycled.

The programme reported here covers the first three Plantings grown between April 1991 and September 1992, where aeroponic, hydroponic and soil based systems were compared. Experience gained from the preliminary investigation in Spring 1991 (Planting I) was used to develop the systems for the main study (Plantings II and III). Details of results from Planting I are presented in Appendix I p.59.

The primary objective of the study was to demonstrate and develop closed recirculation systems for the cultivation of AYR chrysanthemums.

MATERIALS AND METHODS

Treatments/Systems Comparison

Planting II - Winter 1991 and Planting III - Spring 1992

The following four systems were compared:

1. Aeroponic - root moistening system
2. Hydroponic system - Probase base (PB2), Greenbase Ecological Ltd
3. Hydroponic system - sand base (See Appendix II, p.70 for details of specification)
4. Soil - conventional system

Each system had independent supply and control of irrigation/nutrition, with systems 1, 2 & 3 using recirculated solution (see Appendix II, p.70 for details of substrate, equipment and irrigation frequency).

Chapin irrigation was used on systems 2, 3 and 4.

Comparison of irrigation frequency on aeroponic system

Planting III only

a.	'Dutch'	Day	30 sec pulse	-	10 min pause
		Night	30 sec pulse	-	120 min pause
b.	'English'	Day	60 sec pulse	-	5 min pause
		Night	30 sec pulse	-	40 min pause

Comparison of propagation method on aeroponic system:

a. Propagated in peat blocks
b. Propagated in jute modules

Comparison of varieties on each system:

Planting II		**Planting III**	
a.	*Snowdon*	a.	*White Fresco*
b.	*Delta*	b.	*Delta*

Cultural Details

i. Plant material

Cuttings of *Delta* were taken from HRI Efford stock and cuttings of *Snowdon* were purchased from Yoder Toddington Ltd for Planting II.

For Planting III, cuttings of *White Fresco* and *Delta* were purchased from Yoder Toddington Ltd.

ii. Propagation

Cuttings were stuck in peat blocks (5 cm x 5 cm x 3 cm) made from ICI blocking compost with etridiazole as 'Aaterra' WP incorporated at 20g/m^3 (for all systems except aeroponics).

For aeroponic systems half the plants were propagated in jute plugs (4 cm x 2 cm x 1.5 cm, NJI Group, Rijssen, Holland) in module trays and the remainder were propagated in peat blocks as above.

Bench heating was used to achieve a compost temperature of 20°C. Night break lighting during the long day period (14 days) was supplied for 5 hours per night using 100 watt tungsten lamps (8 minutes on, 8 minutes off cycle) to achieve a minimum light level of 100 lux.

After sticking, blocks were covered with clear polythene (supported on hoops approximately 30 cm above cuttings). Covers remained in place for approximately 7 days before removal and weaning of plants.

Jute plugs were irrigated with dilute nutrient solution (Appendix III, pp.73-75) to achieve EC = 1050μS. The concentration of this solution was increased slightly 3 days prior to planting (EC = 1300μS) in order to acclimatize roots prior to contact with 'full-strength' nutrient solution.

All cuttings were sprayed with mancozeb as Karamate Dry Flow at 2.0 g/l and deltamethrin as Decis at 0.7 ml/l four days after sticking and with iprodione as Rovral WP at 0.5 g/l two days prior to planting.

iii. Crop schedule

Planting II

Rooted cuttings in jute plugs and peat blocks were planted out in Week 44 at 85% density. Jute plugs were planted three days ahead of peat blocks. (See Appendix II, p.71 for details).

Plants were given long day lighting (ie. night break for 5 hours per night, 100 watt tungsten, 8 minutes on, 8 minutes off cycle) for 4 weeks to week 48 (29.11.91).

They were then exposed to a period of 18 short days calculated according to P.A.R. light integral (to 17.12.91), and averaged to accommodate the differing speeds of bud initiation and early development of *Snowdon* (16 day SD) and *Delta* (20 day SD).

A 10-day interruption was given (18.12.91 - 28.12.91) prior to return to short day environment until flowering.

Planting III

Rooted cuttings in jute plugs and peat blocks were planted out in Week 10. Jute plugs and peat blocks were planted on the same day. (See Appendix II, p.72 for details).

To aid initial establishment non-woven polypropylene fleece (Agryl) was placed over the beds and moistened to maintain high humidity for several days post-planting. (Overhead mist lines were also used, in particular on the aeroponics beds, in the early stages of crop establishment).

Plants were given long day lighting for 17 days (to 5.4.92). They were then exposed to a 13 day - period of short days, based on P.A.R. light integral, (5.4.92 - 17.4.92).

A 5-day interruption was given (18.4.92 - 23.4.92) prior to return to short day environment until flowering.

iv. Glasshouse environment

The temperature regime for Planting II was set at 18°C day and night with ventilation at 21°C. Thermal screen covers were drawn across ½ hour after sunset and removed at sunrise.

The temperature regime for Planting III was set at 16°C day and night with ventilation at 19°C. Blackout screen covers were drawn across at 6.00 pm and removed at 7.00 am.

Enrichment with pure CO_2 to 1000 vpm was given when vents were less than 5% open and 500 vpm at or above 5% open (Planting II). Similar CO_2 enrichment was given to Planting III at $<5\%$ vent but no enrichment was given when venting was greater than 5%.

v. Nutrition, growth regulation and pest and disease control.

Aeroponic, hydroponic and soil systems received nutrient solutions as outlined in Appendix III, p.73-75.

Growth of *Snowdon* in Planting II was regulated using daminozide (Alar) sprays 2 weeks after planting (1.0 g/l), at start of short days (1.0 g/l) and at start of interruption (0.5 g/l).

Routine chemical programme for control of American Serpentine Leaf Miner was in effect at the time of Planting II i.e. triazophos as Hostathion at 0.5 ml/l and deltamethrin fog (Decis, 70 ml, Nevolin, 1000 ml).

Etridiazole as Aaterra WP at 60 g/1000 litre of solution for control of *Pythium* was added at planting to the recirculating nutrient solution and replenished after 6 weeks.

Assessments

The following records were taken throughout the trials:

Planting II

i. Weekly nutrient analysis of solution

ii. Root length and fresh and dry weight were assessed at key developmental stages:

   a. 2 days before start of short days
   b. 1 week after start of short days
   c. At start of interruption
   d. At end of interruption
   e. At maturity

   (Additional records not specified in the original contract were taken from these destructive samples. These included plant height, fresh and dry weight of shoots and leaf mineral analysis).

iii. Disease assessment of roots:

   At each of the assessment stages outlined above, sub-samples of roots were examined for the presence of *Pythium*.

iv. Records taken at marketing included:

a. Crop duration

b. Crop height (cm)

c. Grade-out: number of stems in marketable grades 10, 13, 16, 19,22 and 25 and waste.

d. Shelf-life: time taken for flower stems to deteriorate from stage 1 (fully expanded flowers) to stages 2 and 3 (ie. partial and complete deterioration).

Shelf-life conditions for AYR sprays were as follows:

On harvest, 5 stems were placed in a sleeve and packed in marketing boxes.

Day 1	Dry storage at 2-5°C (cold room)
Day 2	Dry storage at ambient 10-15°C (packing shed)
Day 3	Stems were recut (3-5 cm removed) and placed in plain water - no leaves below water level.
Shelf-life	To simulate home conditions flowers were exposed to 20°C D/N and 70-80° RH with fluorescent lighting for 12 hours.

v. Photographic record as appropriate

vii. Environmental records included temperatures of soil, substrate and nutrient solution.

Planting III

i. Weekly mineral analysis of solution and metering of volumes of nutrient and water supplied to each system.

ii. Plant assessment at key developmental stages in crop schedule included:

Shoot length (cm), shoot fresh and dry weight (g), leaf area (cm^2) and leaf mineral analysis and photographic record of comparative root growth at:

a. 2 days before start of short days

b. At start of interruption

c. One week after end of interruption

d. At maturity

iii. Disease assessment of roots at planting and at each of the assessment stages outlined above. Sub-samples of root were examined for the presence of *Pythium*.

iv. Record at marketing stage as for Planting II

a. Crop duration

b. Crop height (cm)

c. Grade-out

d. Shelf-life

v. Photographic record as appropriate

vii. Environmental records included temperatures of soil, substrate and nutrient solutions.

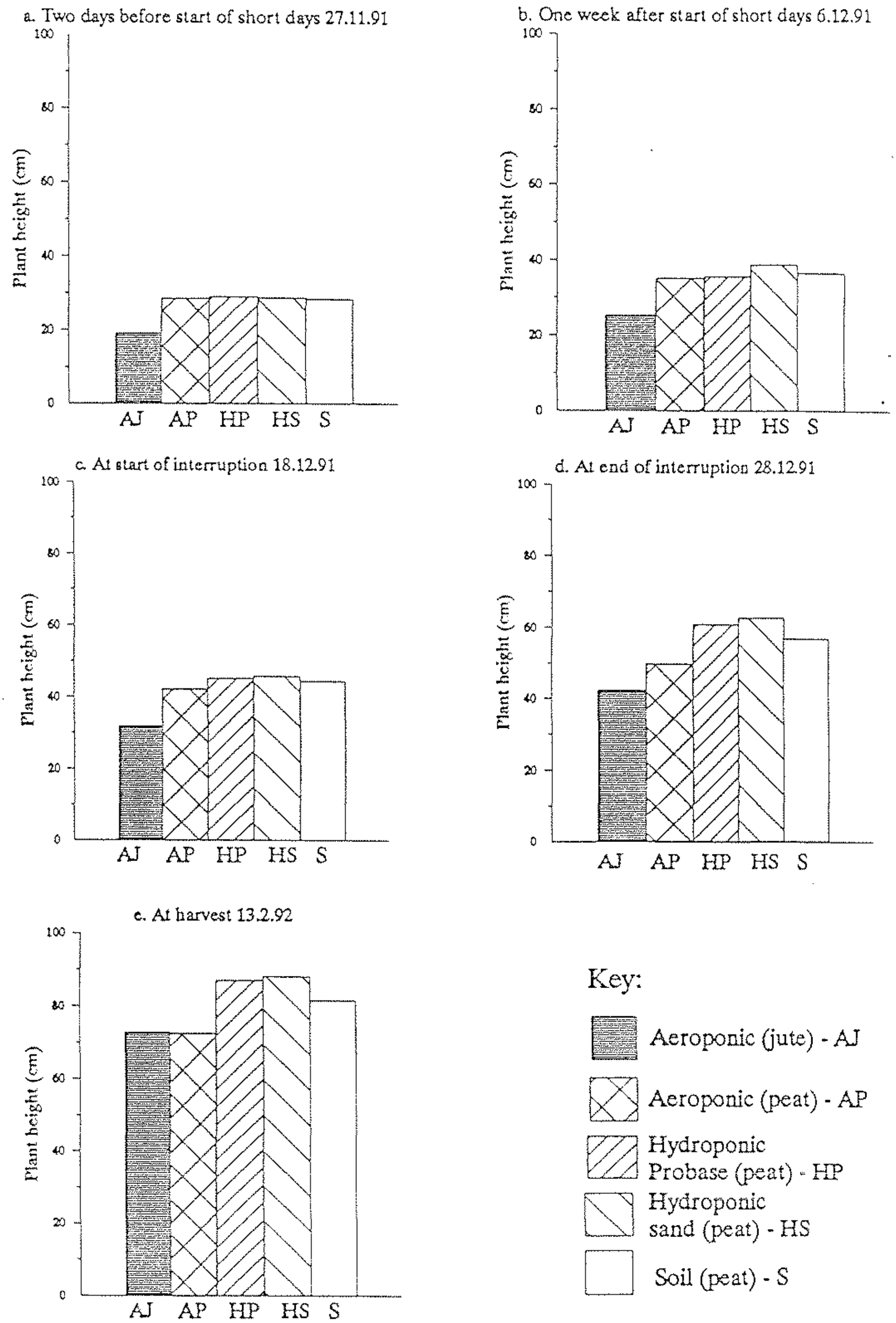
Statistical Analyses

Since there was no replication of treatment systems only limited statistical analyses (analysis of variance) could be carried out to examine the influence of systems, varieties and propagation method (jute plugs or peat blocks) on productivity.

RESULTS

PLANTING II

Figure 1. Systems comparison of plant height (cm) of Delta at key stages throughout the life of the crop. Planting II



RESULTS

PLANTING II

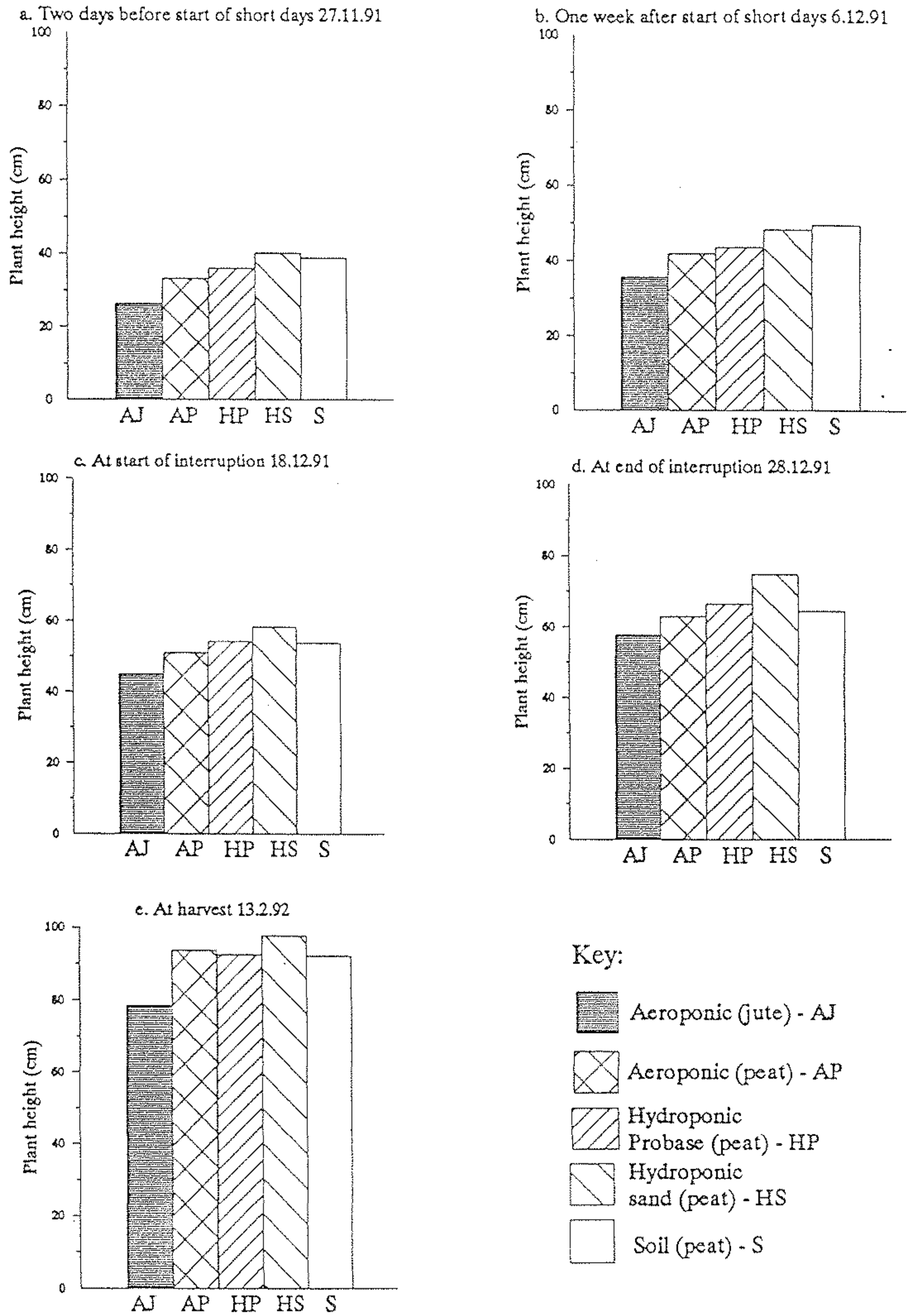
Plant height - *Delta*

Figure 1 and Appendix IV, Table 1, p.76.

In the early stages of plant growth, plant height of *Delta* was comparable on all systems, Fig 1a. Those which had been propagated in jute plugs had had a difficult establishment period and were shorter. During the short day period, hydroponically grown plants began to show an advantage, Fig 1b, Fig 1c.

Marked extension growth occurred during the interuption with the hydroponic sand crop in particular approximately 6 cm taller than the conventional soil grown crop, Fig 1d. This trend was maintained through to harvest, Fig 1e.

Figure 2. Systems comparison of plant height (cm) of Snowdon at key stages throughout the life of the crop. Planting II



Plant height - ***Snowdon***

Figure 2 and Appendix IV, Table 2, p.77.

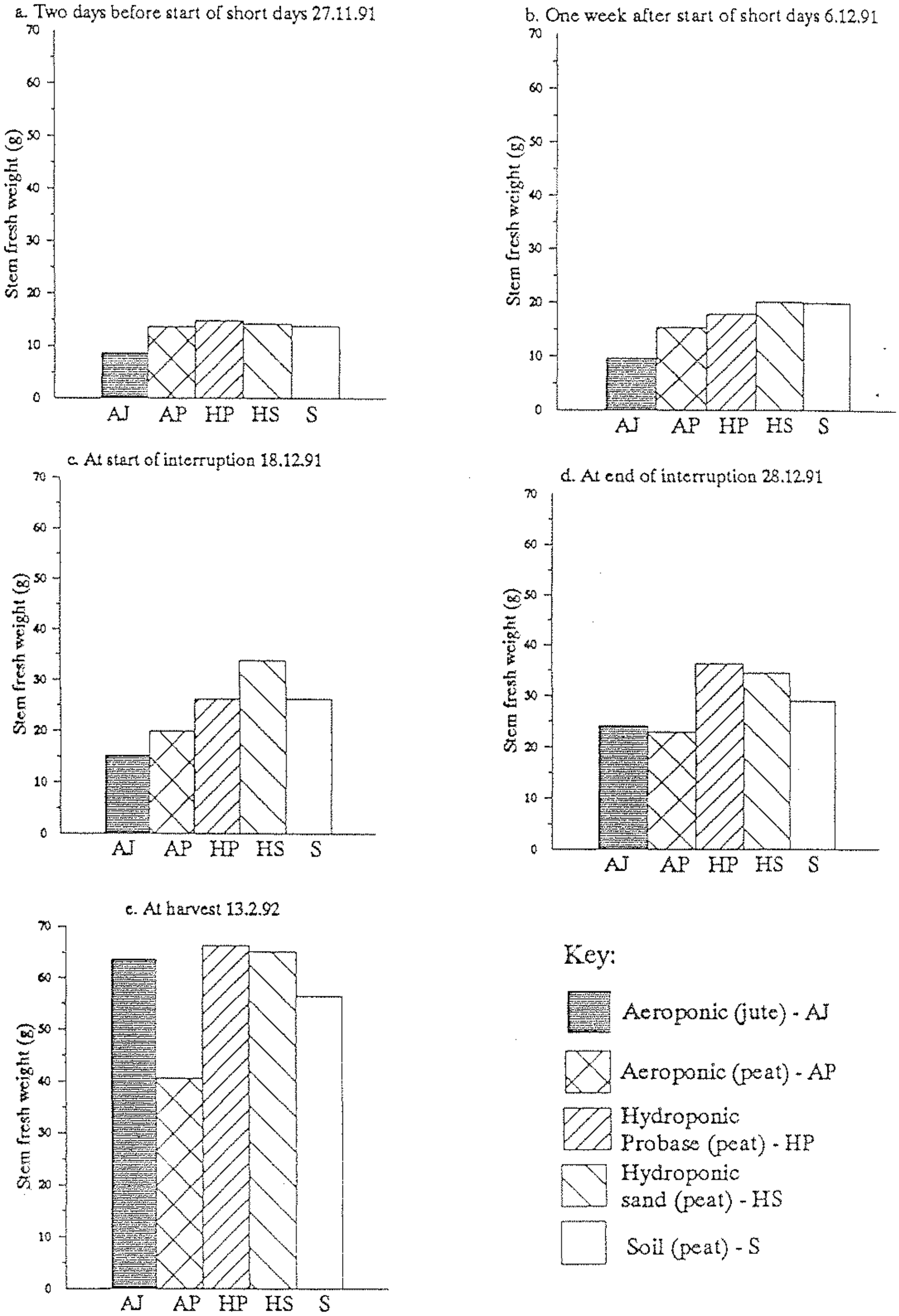
Snowdon established well on hydroponic sand beds during the early stages of the trial as shown by plant height records, Fig 2a.

Difficulties in establishment on aeroponic system of plants propagated in jute plugs was again reflected by shorter stems. While hydroponic sand and conventional soil systems displayed similar growth during the short day period, Fig 2b, greater extension growth was recorded for hydroponically grown crops during the interruption period, Fig 2c and Fig 2d.

The sand system in particular produced plants which were approximately 10 cm taller than the conventional soil grown plants, Fig 2d.

At harvest tallest plants were obtained from hydroponic sand beds, Fig 2e. Comparable heights were achieved on the remaining systems with the exception of aeroponic jute which had suffered during early establishment, Fig 2e.

Figure 3. Systems comparison of stem fresh weight (g) of Delta at key stages throughout the life of the crop. Planting II



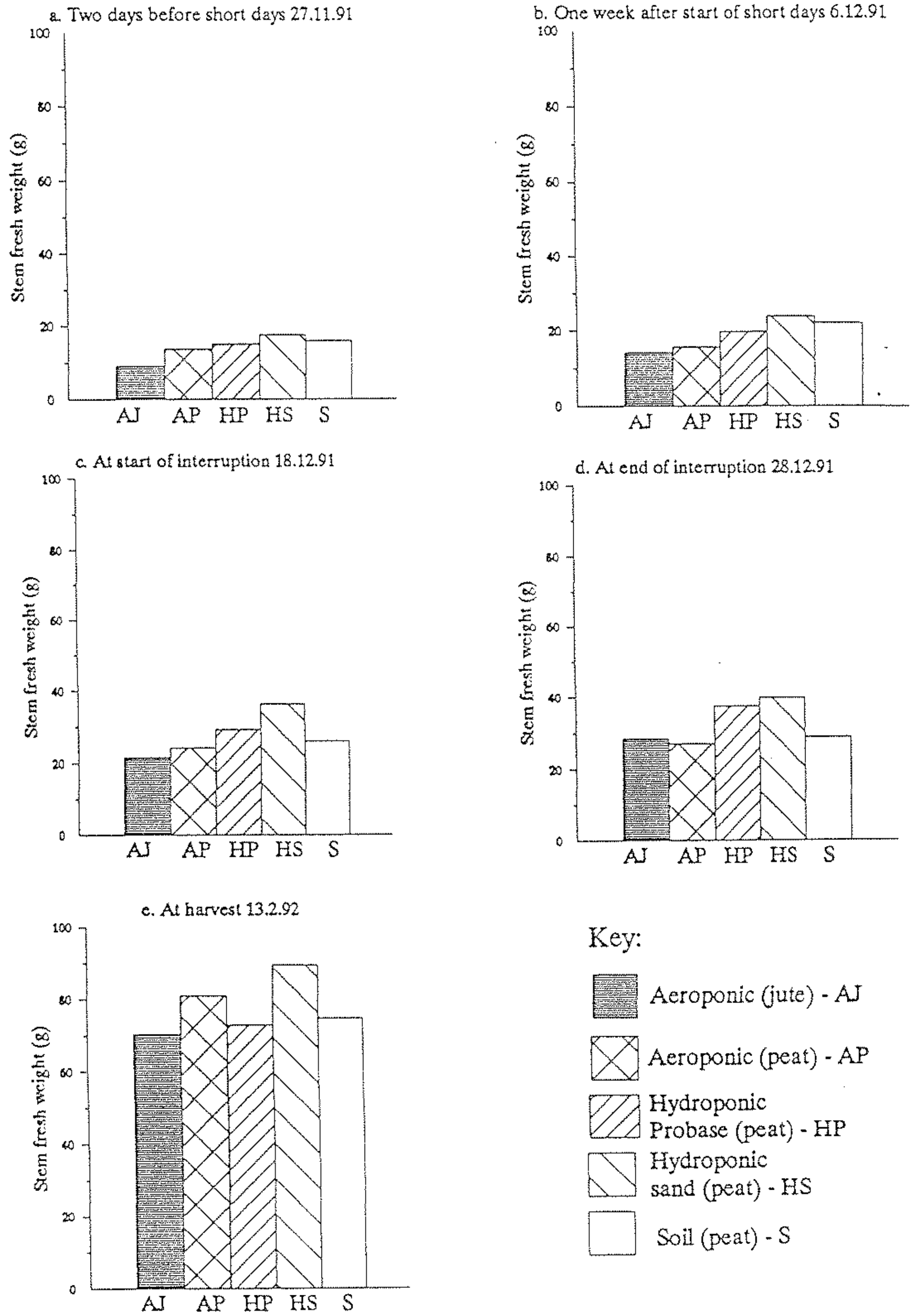
Stem fresh weight - *Delta*

Figure 3 and Appendix IV, Table 3, p.78.

Comparable plant fresh weights were recorded on all systems (except aeroponic jute) in the early stages of crop development, Fig 3a, but differences became marked in the later stages, Fig 3b and Fig 3c.

Plants from the hydroponic sand system were heaviest at start of the interruption Fig 3c, but the plants on hydroponic-Probase system benefitted particularly well from the interruption so that by the end of this period both hydroponic systems yielded the greatest fresh weights, Fig 3d. This trend was maintained through to harvest, Fig 3e.

Figure 4. Systems comparison of stem fresh weight of Snowdon at key stages throughout the life of the crop. Planting II



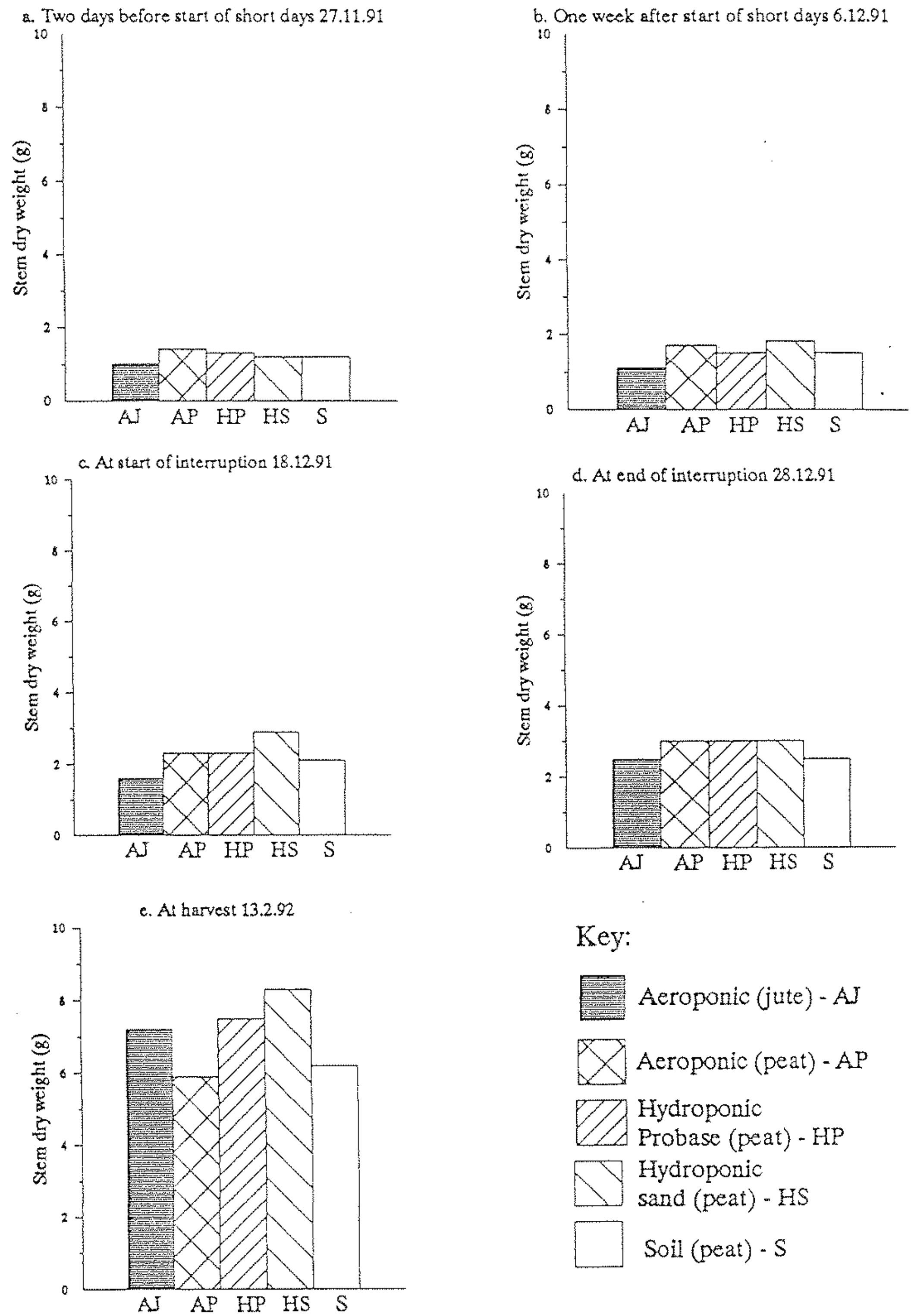
Stem fresh weight - *Snowdon*

Figure 4 and Appendix IV, Table 4, p.79.

In the early stages of crop development, heaviest fresh weights of *Snowdon* were recorded on hydroponic sand beds, Fig 4a, with lightest stems recorded for aeroponic (jute) samples. This trend followed through into short days, Fig 4b, and by the start of the interruption hydroponic systems and in particular sand, yielded the heaviest plants, Fig 4c.

As with *Delta* plants on the hydroponic Probase system appeared to benefit particularly well from the interruption so that by the end of this period greatest fresh weights were recorded from both hydroponic systems Fig 4d. At harvest, however, only the hydroponic sand and aeroponic (peat) samples were heavier than the conventional soil grown crop, Fig 4e.

Figure 5. Systems comparison of stem dry weight (g) of Delta at key stages throughout the life of the crop. Planting II



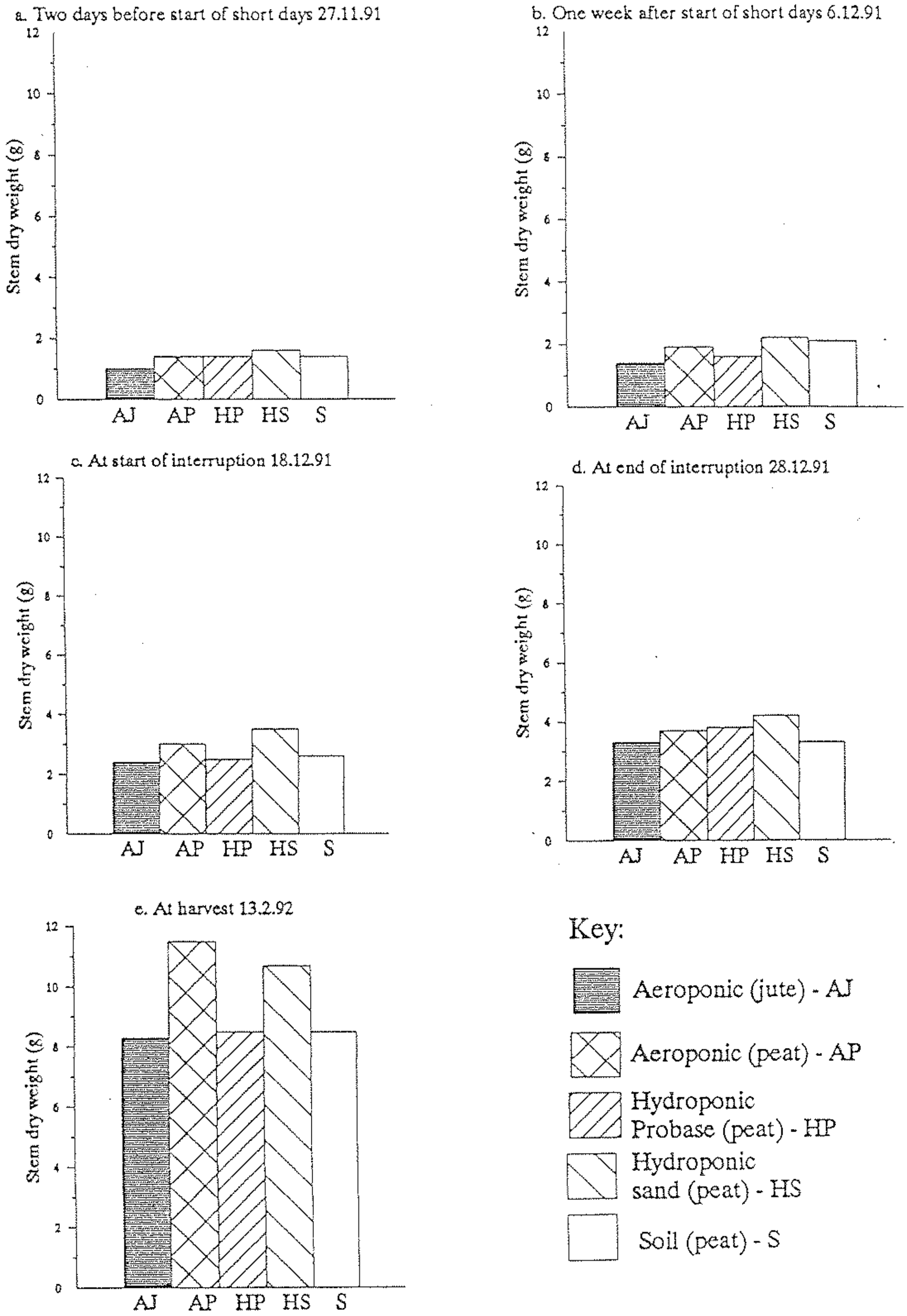
Stem dry weight - *Delta*

Figure 5 and Appendix IV, Table 5, p.80.

The trends observed in fresh weight records relative to system were reflected in the dry weight analysis, Fig 5, with greatest dry weights at start of interruption recorded for samples taken from the hydroponic sand system, Fig 5c.

Little difference in dry weight was apparent at the end of the interruption (except for aeroponic jute and soil which were lighter, Fig 5d). At harvest, both hydroponic systems yielded greater dry weights than the soil, Fig 5e.

Figure 6. Systems comparison of stem dry weight (g) of Snowdon at key stages throughout the life of the crop. Planting II



Stem dry weight - *Snowdon*

Figure 6 and Appendix IV, Table 6, p.81.

As for *Delta*, the trends in fresh weight records were reflected by dry weight assessment, Fig 6, with greatest dry weights from hydroponic sand system at the start of the interruption, Fig 6c, and from both hydroponic systems, sand and Probase, at the end of the interruption, Fig 6d.

At harvest the dry weights from hydroponic sand and aeroponic (peat) systems exceeded those of both hydroponic-probase and soil grown crops, Fig 6e.

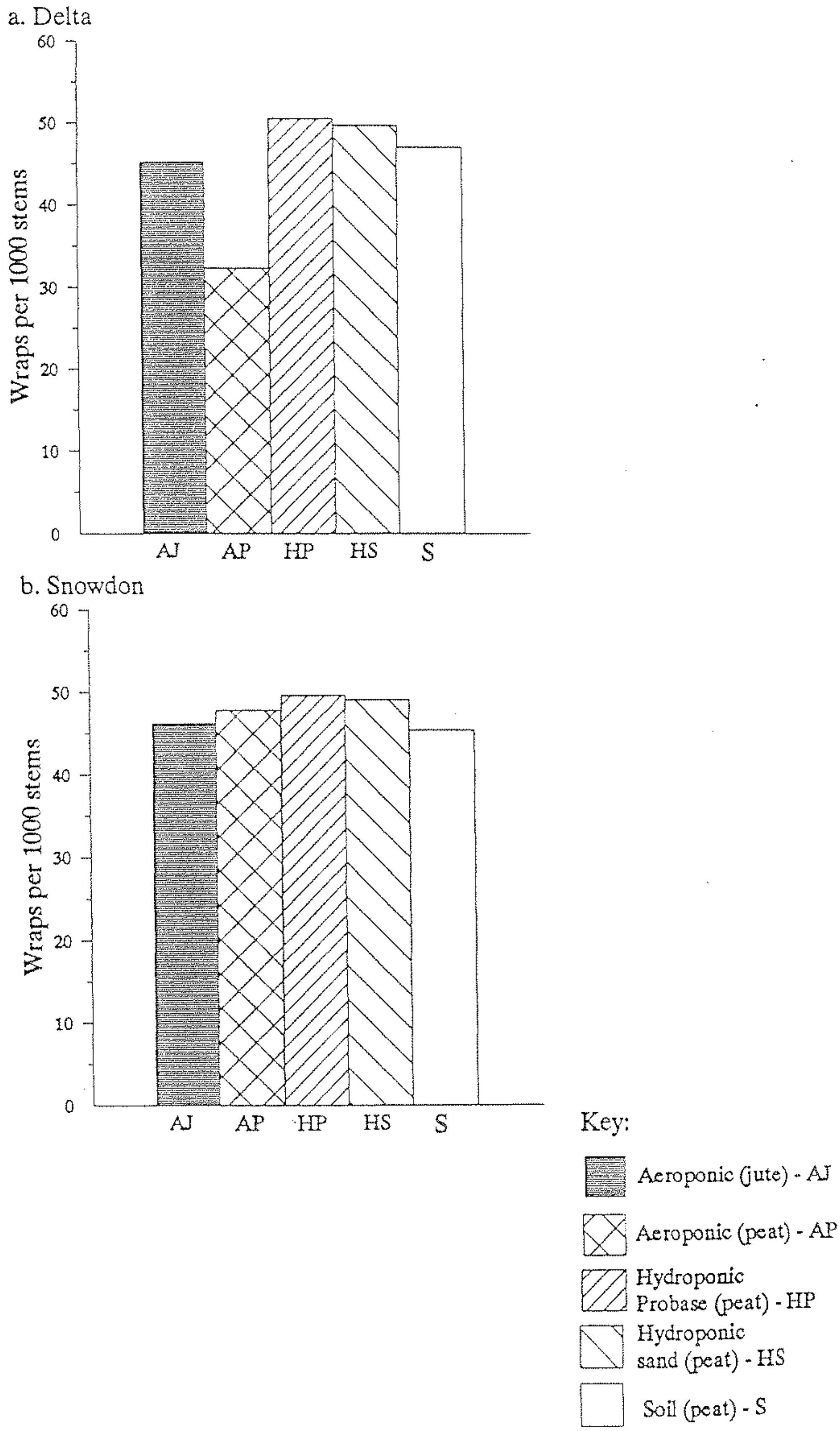
Root growth assessments - *Delta* and *Snowdon*

Appendix IV, Tables 7-12, pp.82-87.

Extensive and elongated root systems were produced by both *Snowdon* and *Delta* in response to aeroponic production, in particular where jute was used as the propagation medium. Much of the root development occurred first in the initial long day period and again between the end of the interruption and harvest. A similar pattern of root development over time took place in the substrate based and conventional soil system but root development was much less extensive.

These results were also reflected by fresh and dry weight assessments, with heaviest root systems being recorded from aeroponic-jute samples.

Figure 7 . Systems comparison of grade out at harvest
for Delta and Snowdon.
Planting II



Root disease assessments - *Delta* and *Snowdon*

Appendix IV, Tables 13-18, pp.88-93.

The percentage of roots of *Delta* showing discolouration and *Pythium* type growth was high in the aeroponic and hydroponic systems during the early stages of establishment and by the short day period all systems, including soil, showed a high level of disease present, Table 15. As the crop matured the level of disease appeared to diminish particularly for the hydroponic sand and soil systems.

Recovery of *Pythium* type organisms from roots of *Snowdon* was very variable, Table 16, but roots which had been incubated in water and scored for sporangial development showed similar trends to *Delta* ie. high levels of pathogens were recovered during the long day period but then diminished rapidly, Table 18.

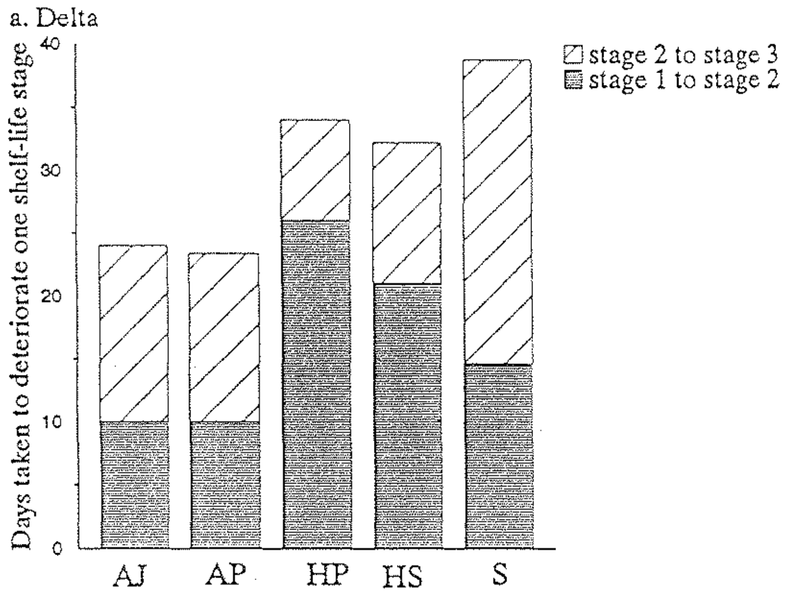
Crop duration and grade out - *Delta* and *Snowdon*

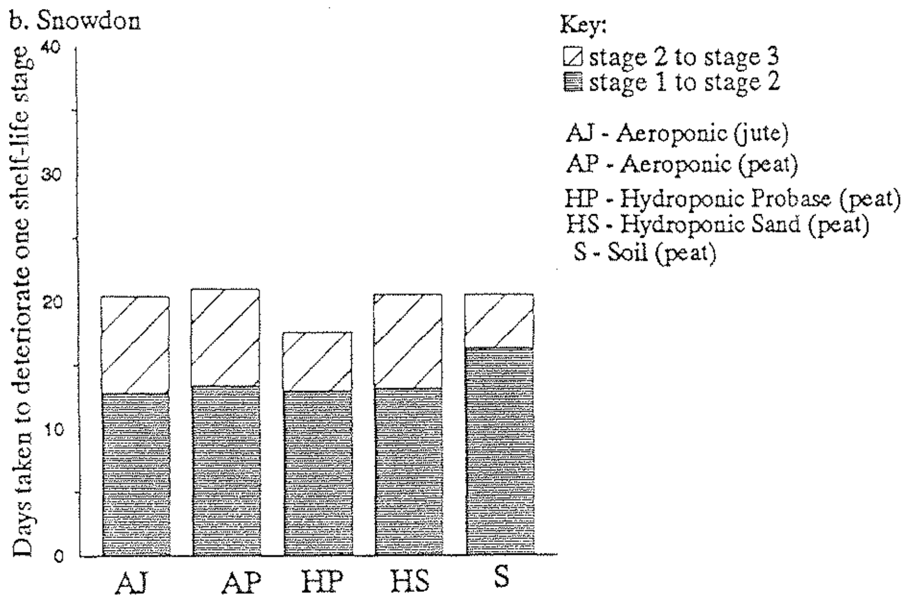
Figure 7 and Appendix IV, Table 19, p.94.

Hydroponic systems (both sand and Probase) yielded the greatest number of wraps per 1000 stems planted for both *Delta*, Fig 7a, and *Snowdon*, Fig 7b, reflecting the overall performance which had been displayed by height and weight records. Taller thicker stems with larger leaves were produced on these systems.

Crop duration was similar across all systems, with *Delta* flowering first ahead of *Snowdon*.

Figure 8. Effects of production system on shelf-life of Delta and Snowdon.
Planting II





Shelf-life - *Delta* and *Snowdon*

Figure 8 and Appendix IV, Table 20, p.95.

Shelf-life performance of *Delta* grown hydroponically was particularly good in the early stages but soil grown crops appeared to hold better in the later stages and had the best overall shelf-life, Fig 8a. Shelf-life of *Snowdon* grown hydroponically in sand was as good as that of the conventional soil grown crop, Fig 8b.

Statistical systems comparison - *Delta* and *Snowdon*

Appendix IV, Table 21, p.96.

Owing to variability within plots and small sample size, no statistically significant difference between treatments could be identified.

Nutrient analyses

Appendix IV, Tables 22-27, pp.97-102.

Conductivity of hydroponic solutions was reasonably well maintained within the range 1500-2000 microsiemens (μS) at 20°C although the aeroponic solution was more difficult to stabilise particularly during the early period of establishment. Phosphate levels in the Probase recirculating solution were lower than in the other systems solutions. Nitrate levels were maintained relatively close to target throughout the life of the crop.

Concentration of minor elements, in particular iron, zinc and manganese, was slightly high in the aeroponic solution whereas magnesium and manganese levels were lower in the Probase recirculating solution.

Leaf analyses

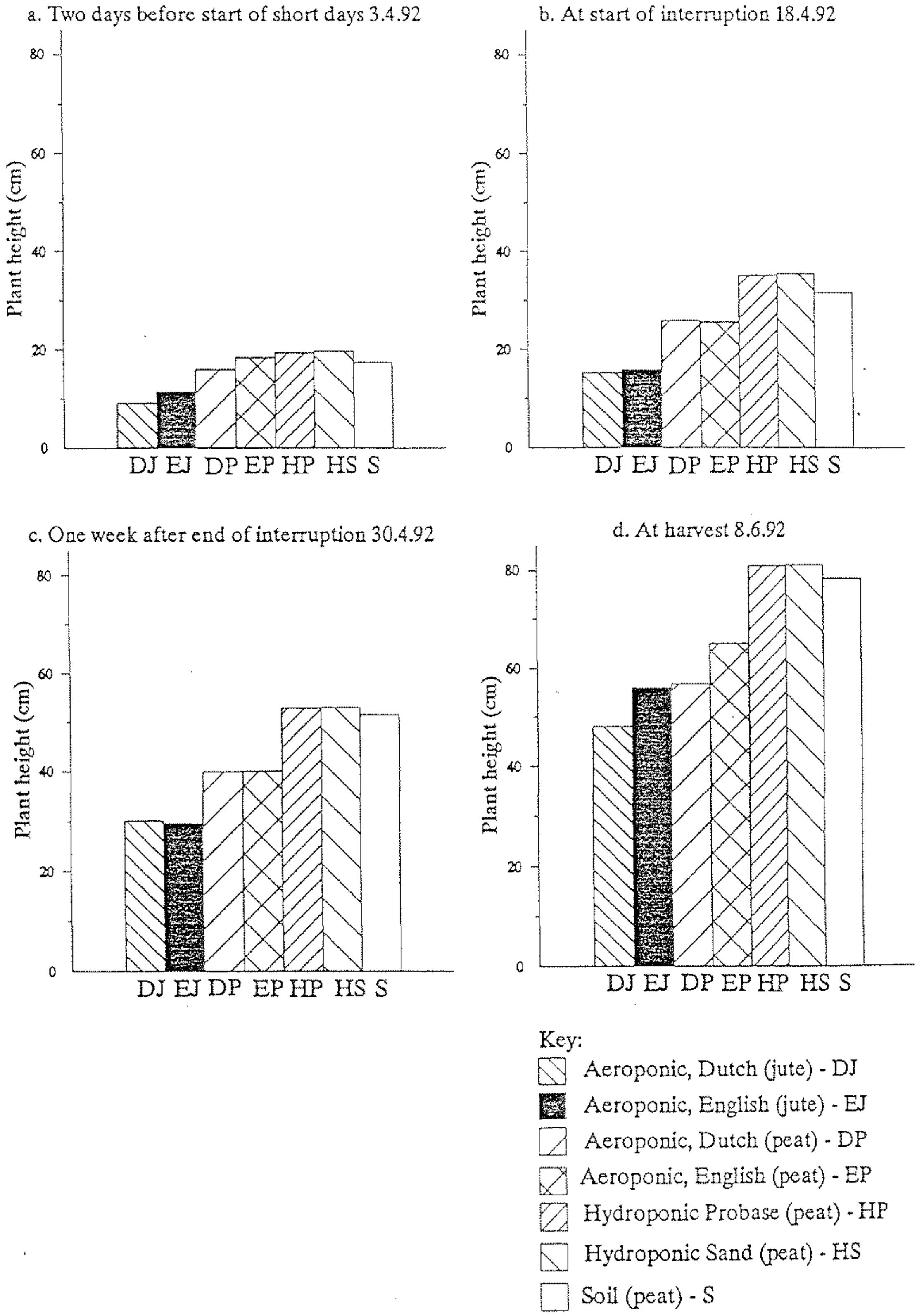
Appendix IV, Tables 28-31, pp.103-106.

Satisfactory levels of % N, % P, % K and % Mg were achieved throughout the life of the crop irrespective of system although % Mn levels were higher for the soil grown crop than for the hydroponically grown crop.

RESULTS

PLANTING III

Figure 9. Systems comparison of plant height (cm) of Delta at key stages throughout the life of the crop. Planting III



PLANTING III

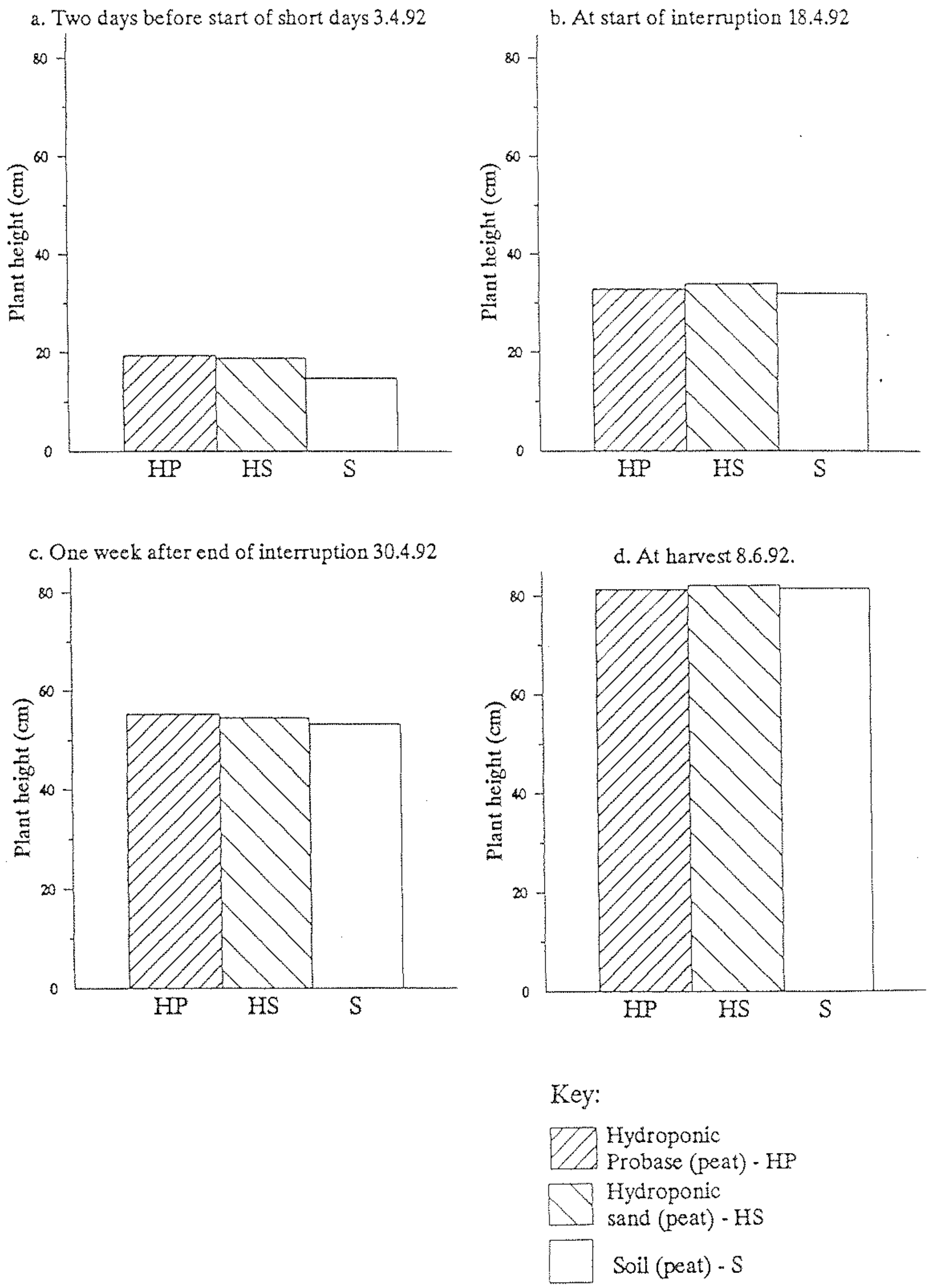
Plant height - *Delta*

Figure 9 and Appendix V, Table 1, p.107.

Plants grown hydroponically on sand or Probase established quickly and were taller than conventionally soil grown plants at the end of the long day period, Fig 9a. They maintained this height differential throughout the interruption period, Fig 9b, Fig 9c and by harvest were still taller, by 2 cm, than the conventional crop, Fig 9d.

Aeroponically grown plants, on the other hand, were difficult to establish. Plants were particularly short where they had been propagated in jute plugs or were subjected to infrequent root misting (Dutch regime), Fig 9a, Fig 9b. Moderate growth occurred during the interruption, Fig 9c. By harvest plants grown aeroponically in the 'English' regime with peat as the propagation medium were 15 cm taller than plants from the 'Dutch' regime which had been propagated in jute plugs, Fig 9d, although they were still 13-14 cm shorter than the conventional soil grown crop.

Figure 10. Systems comparison of plant height (cm) of White Fresco at key stages throughout the life of the crop. Planting III

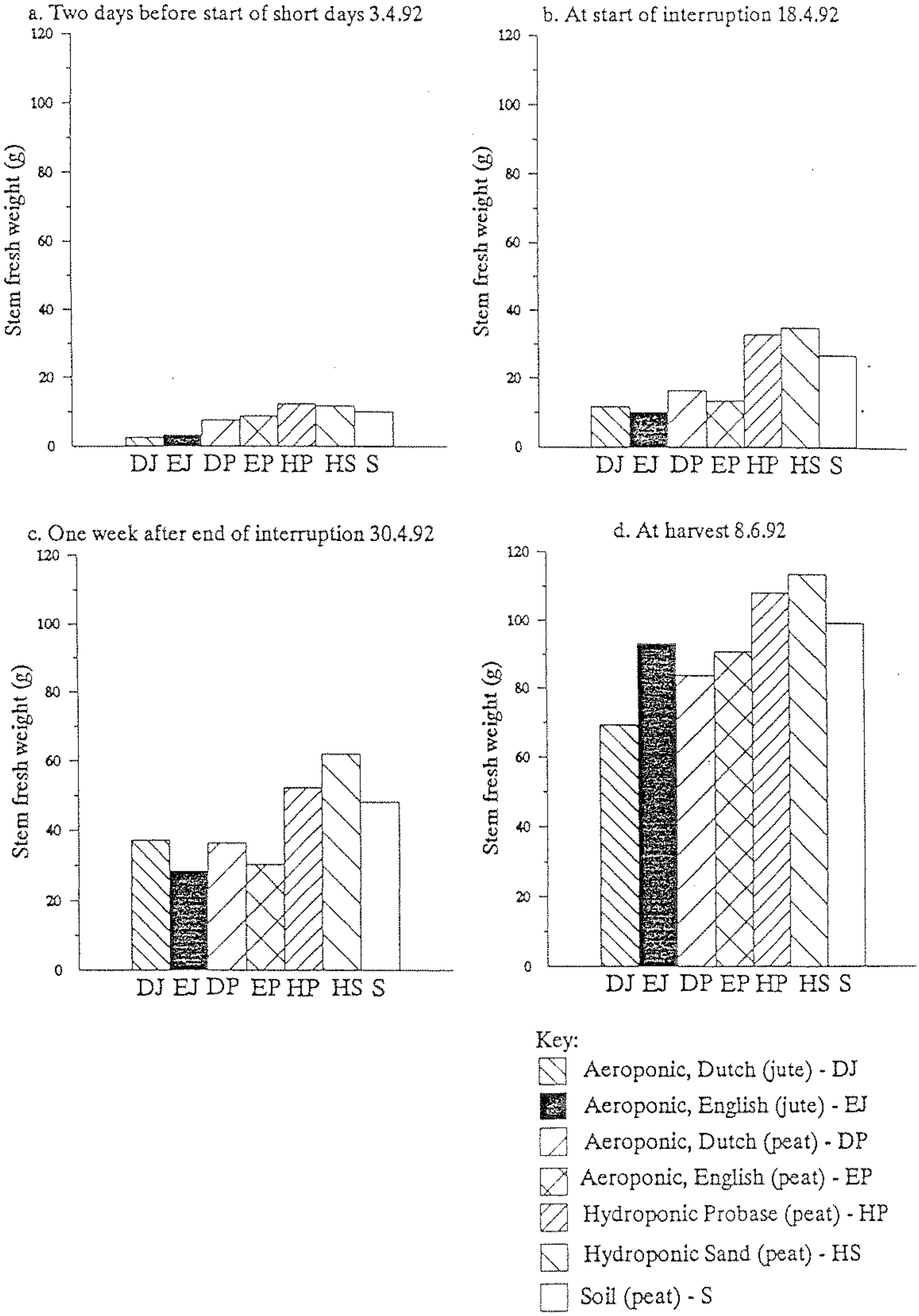


Plant height - *White Fresco*

Figure 10 and Appendix V, Table 2, p.108.

In the early stages of plant growth, *White Fresco* was tallest when grown hydroponically on sand or Probase; up to 5 cm taller than the soil grown crop, Fig 10a. One week after the end of interruption, however, the soil grown crop was only 1-2 cm shorter than the hydroponically grown plants, Fig 10c. This trend was maintained through to harvest, Fig 10d.

Figure 11. Systems comparison of stem fresh weight (g) of Delta at key stages throughout the life of the crop. Planting III



Stem fresh weight - *Delta*

Figure 11 and Appendix V, Table 3, p.109.

Throughout the life of the crop plants grown hydroponically on sand or Probase displayed the greatest stem fresh weights. They were up to 14g heavier than the soil grown crop, Fig 11. From the start of interruption through to harvest, stems from the hydroponic sand system were also heavier by 6-10g than the stems from the hydroponic Probase system, Fig 11c, Fig 11d.

Aeroponically grown plants had extremely low fresh weights recorded, especially during the early vegetative stages of growth, reflecting the difficulty of crop establishment in this system, Fig 11a, Fig 11b. Weight gain occurred during the later stages such that by harvest plants propagated in peat blocks and grown in the 'English' regime with frequent root misting had stem weights in the range of 80-90g, Fig 11d.

Figure 12. Systems comparison of stem fresh weight (g) of White Fresco at key stages throughout the life of the crop. Planting III

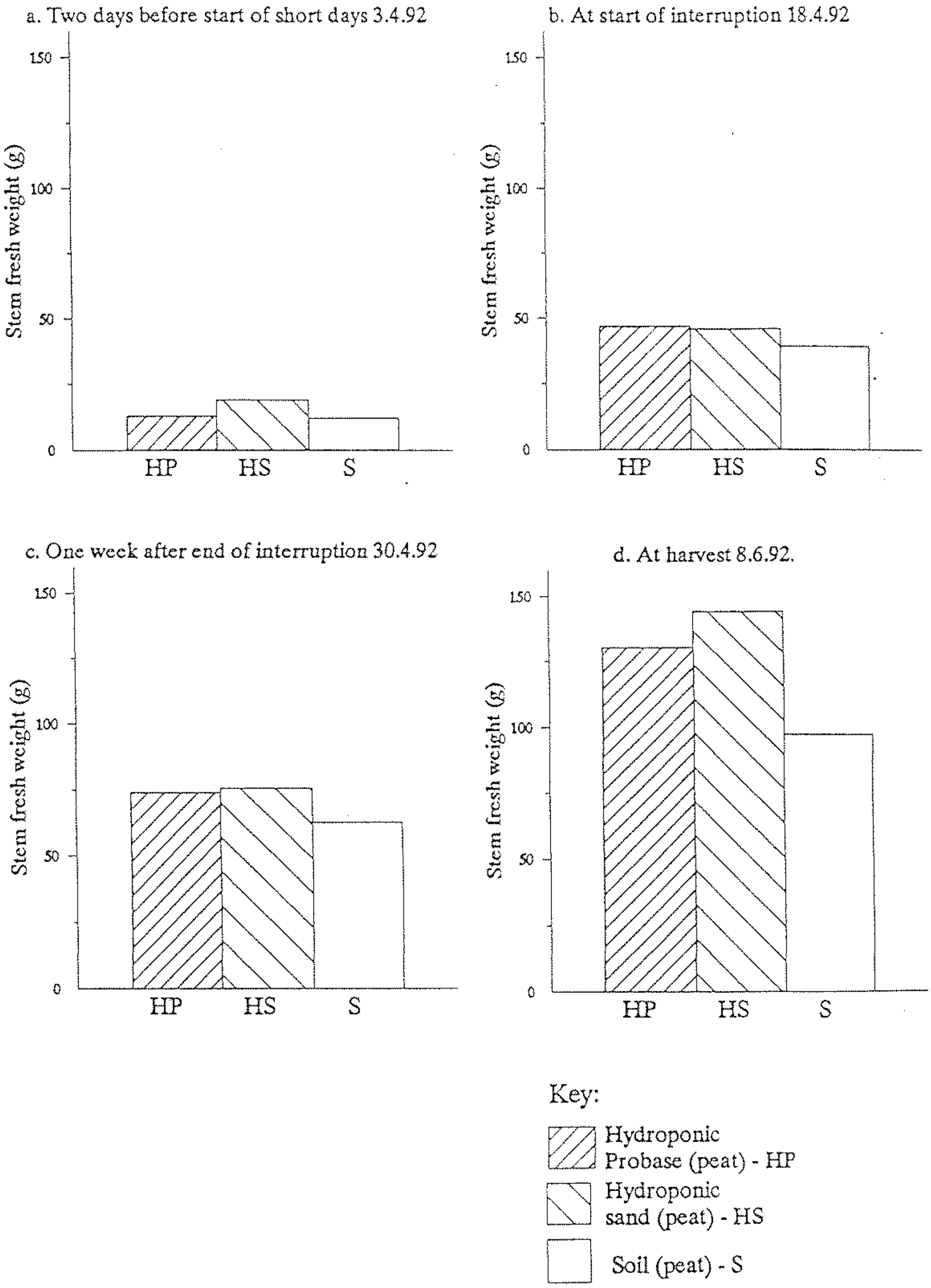
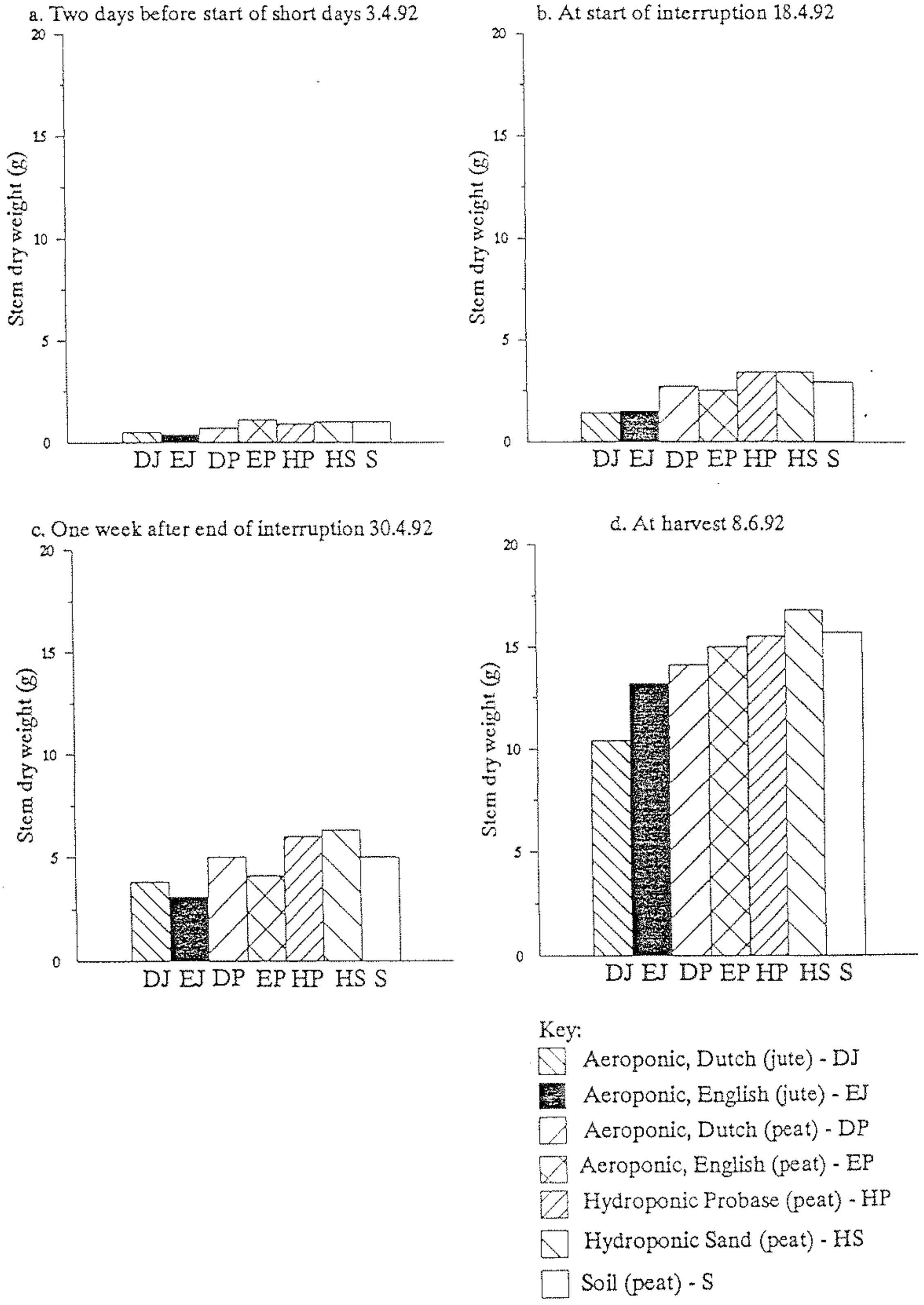


Figure 13. Systems comparison of stem dry weight (g) of Delta at key stages throughout the life of the crop. Planting III



Stem fresh weight - *White Fresco*

Figure 12 and Appendix V, Table 4, p.110.

In the early stages of plant growth, *White Fresco* stems were heaviest when grown hydroponically on sand, Fig 12a. By the start of the interruption fresh weight samples from both hydroponic systems (sand and Probase) were 6-7g heavier than the soil grown crop, Fig 12b, and by one week after the end of the interruption these were both approximately 11g heavier than the soil grown crop, Fig 12c. This trend was maintained through to harvest with hydroponically grown crops weighing 30-45g more than the soil grown crop, Fig 12d. Plants grown on sand were heaviest.

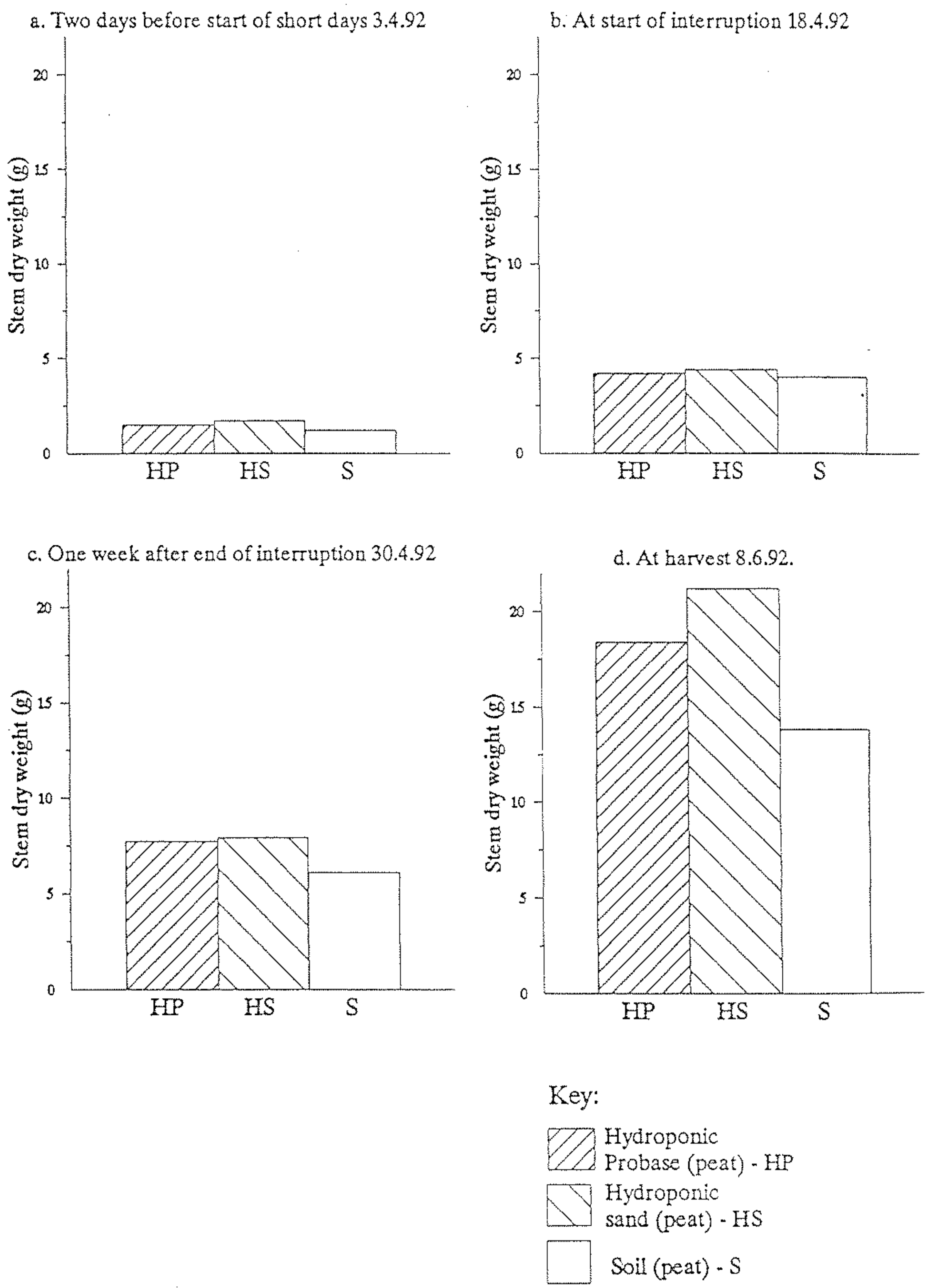
Stem dry weight - *Delta*

Figure 13 and Appendix V, Table 5, p.111.

Stem dry weights for *Delta* reflected the trends displayed by the fresh weight data with plants grown hydroponically having the greatest stem dry weights during the early growing phase, Fig 13a, Fig 13b. In the later stages of the crop stems from the hydroponic sand system were heaviest, Fig 13c. By harvest dry weights of stems from the hydroponic Probase system and soil were comparable, but the hydroponic sand system stems were still the heaviest, Fig 13d.

Dry weights of plants grown aeroponically were particularly low during the initial growing period, increased markedly during the period from the end of interruption through to harvest but at harvest were still lower than the conventional soil grown plants, Fig 13.

Figure 14. Systems comparison of stem dry weight (g) of White Fresco at key stages throughout the life of the crop. Planting III

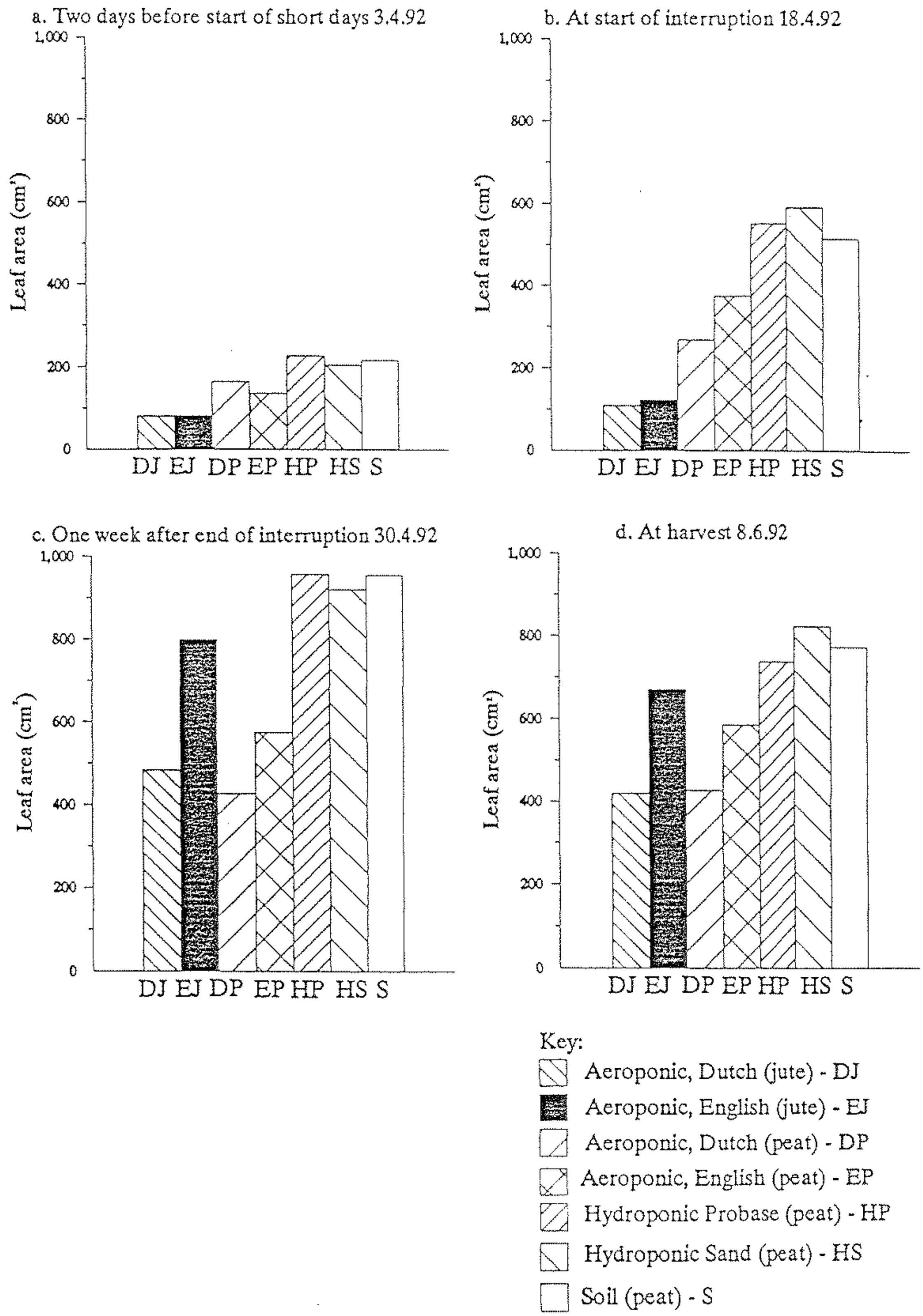


Stem dry weight - *White Fresco*

Figure 14 and Appendix V, Table 6, p.112.

Heaviest dry weights throughout the trial were recorded for *White Fresco* samples taken from the hydroponic sand system, Fig 14. Those from the hydroponic Probase system at harvest were approximately 5g heavier than those from the conventional soil grown crop while those from sand were approximately 7.5g heavier than the samples from soil.

Figure 15. Systems comparison of leaf area (cm²) of Delta at key stages throughout the life of the crop. Planting III



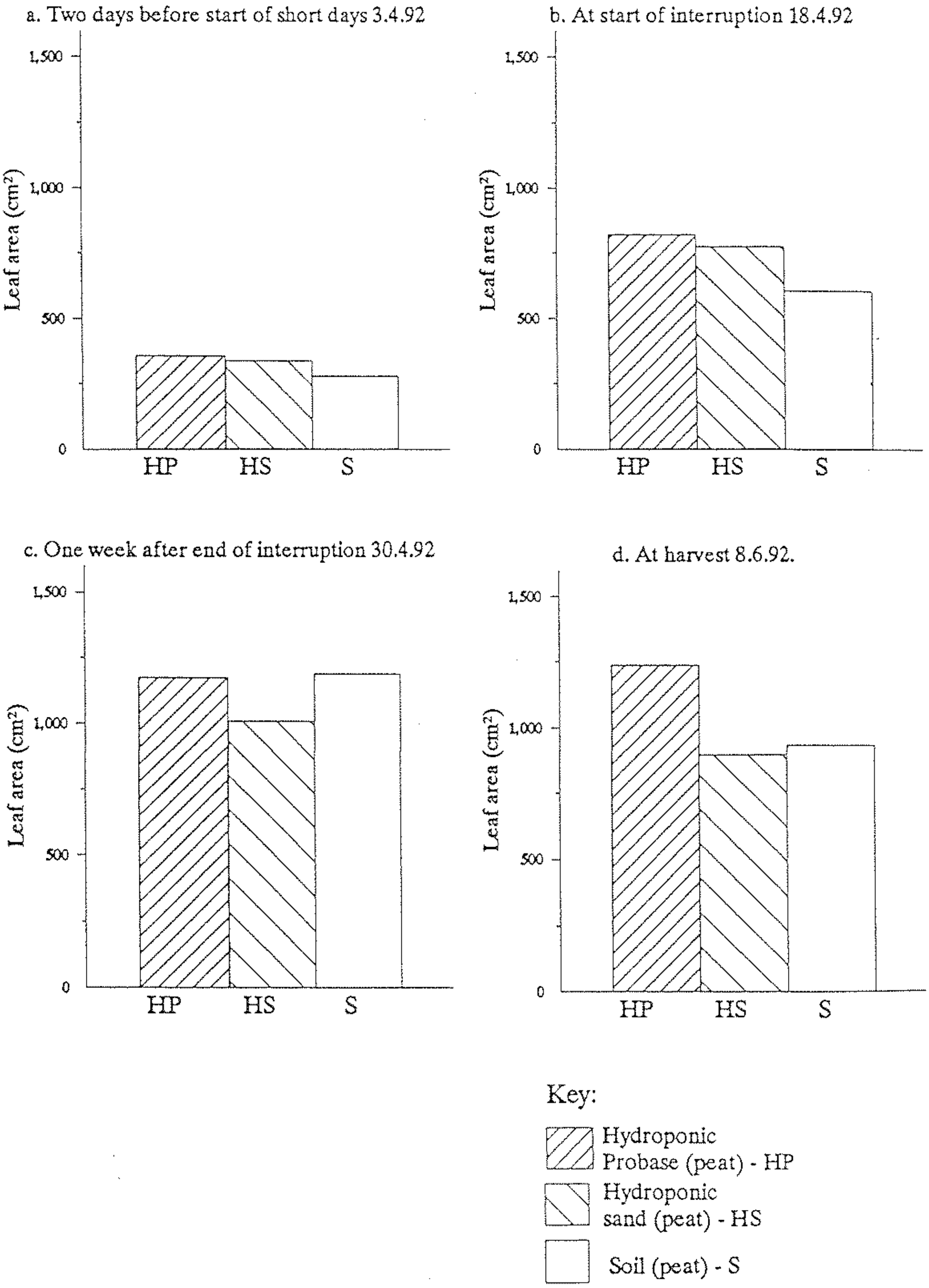
Leaf area - *Delta*

Figure 15 and Appendix V, Table 7, p.113.

Total leaf area, especially at the start of interruption, was greatest for hydroponically grown crops, both sand and Probase, Fig 15. Partial lower leaf loss at maturity accounted for reduction in leaf area assessed at harvest. Poor growth in aeroponic systems was reflected by much smaller leaf area especially during the early part of the trial period, Fig 15a.

Examination of leaf area per cm of stem showed that at harvest, hydroponically grown crops had a much greater leaf area relative to stem height than the soil grown crop, Appendix V, Table 8, p.114.

Figure 16. Systems comparison of leaf area (cm^2) of White Fresco at key stages throughout the life of the crop. Planting III



Leaf area - *White Fresco*

Figure 16 and Appendix V, Table 9, p.115.

Total leaf area was greatest for hydroponically grown *White Fresco* during the early vegetative period and up to the start of interruption, Fig 16a, Fig 16b. The soil grown crop had caught up by the end of the interruption, Fig 16c. Slight lower leaf loss occurred at maturity. Overall greatest leaf area was recorded on samples from the hydroponic Probase system. These results were reflected by the examination of leaf area per cm of stem relative to system. Best overall performance in terms of leaf area was displayed by hydroponic Probase samples, Appendix V, Table 10, p.116.

Root growth and disease assessments - *Delta*

Appendix V, Tables 11 and 12, pp.117-118 and Appendix VI, Plate 4, p.136.

Root growth was monitored by photographic records. As in Planting II the nature of the root system from aeroponically grown plants was very different from roots of plants which had been grown in a substrate based system. 'Aeroponic' roots were extensive, especially where plants had been propagated in jute plugs, whereas roots from plants grown in substrate-based systems were much smaller. Root discoloration of samples taken at intervals throughout the life of the crop was extremely variable, as was recovery of fungal pathogens from the root systems.

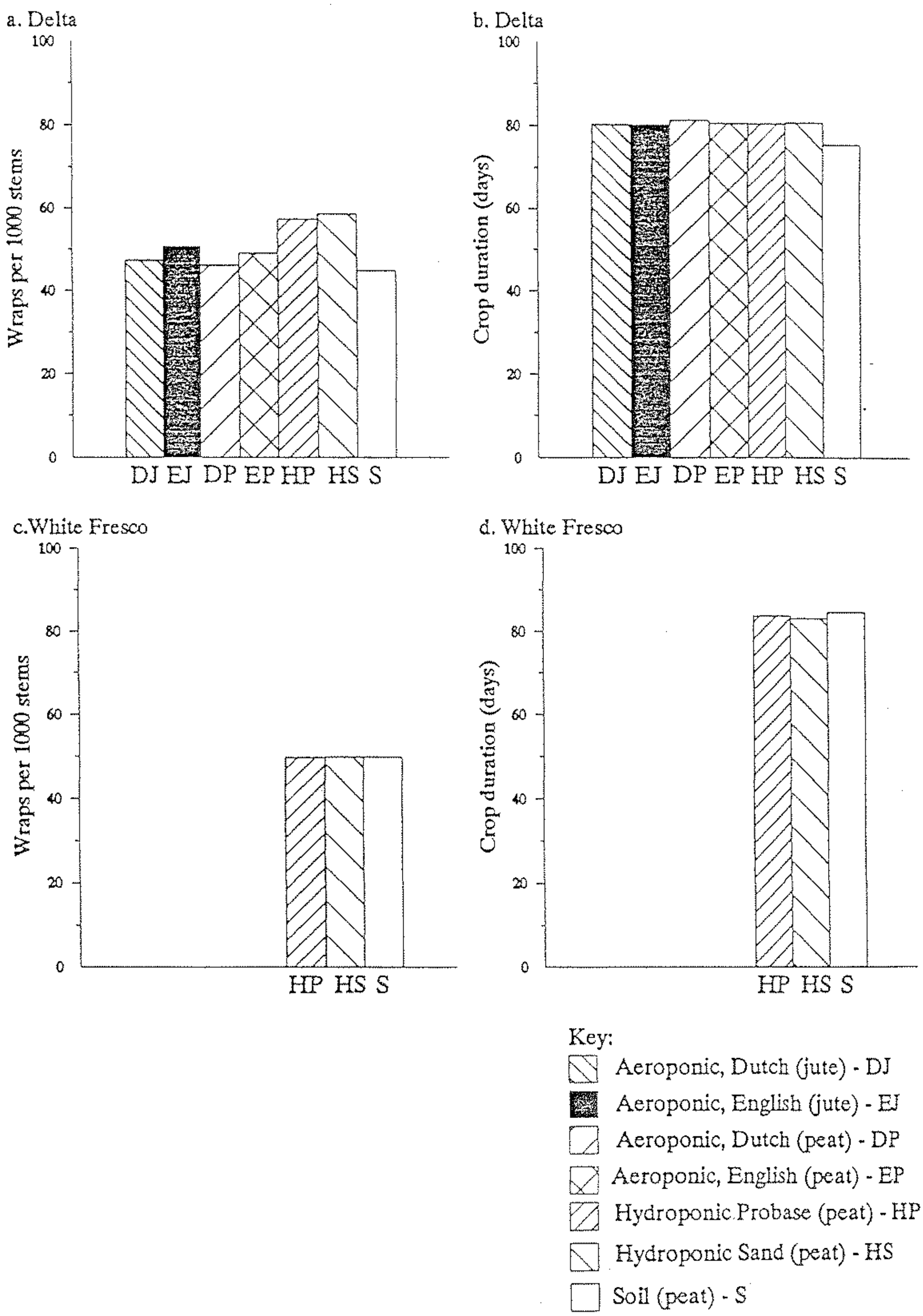
Root growth and disease assessments - *White Fresco*

Appendix V, Tables 13 and 14, pp.119-120 and Appendix VI, Plate 4, p.136.

Most extensive root growth of *White Fresco* took place in the sand-based system.

Root discoloration was most marked in the samples taken at the start of the interruption, in particular in the samples taken from soil. There was no consistent pattern of recovery of fungal pathogens from samples taken throughout the life of the crop, apart from the observation that pathogen recovery was lowest at harvest.

Figure 17. Systems comparison of grade out and total crop duration for Delta and White Fresco Planting III.



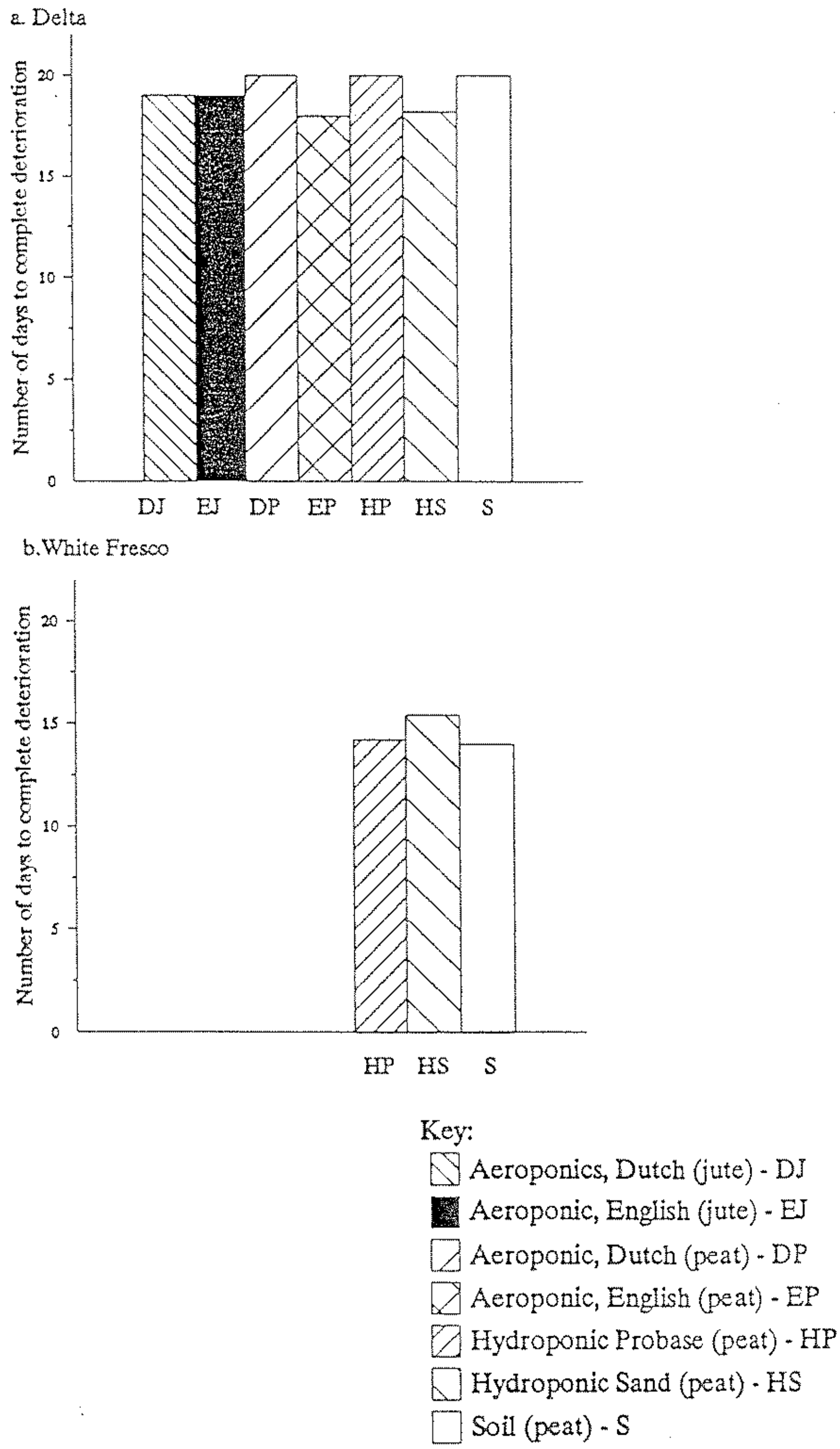
Crop duration and grade out - *Delta* and *White Fresco*

Figure 17 and Appendix V, Table 15, p.121.

Hydroponic systems, in particular sand, yielded the greatest number of wraps per 1000 stems planted of *Delta*, Fig 17a. These systems produced up to 14 more wraps per 1000 stems than the soil grown crop although the latter flowered several days earlier than the hydroponically grown crops, Fig 17b.

White Fresco, on the other hand, produced numbers of wraps per 1000 stems comparable with the soil grown crop, Fig 17c, but this time the hydroponic crops flowered slightly earlier than the soil grown crop, Fig 17d.

Figure 18. Systems comparison of number of days taken for cut stems to reach complete deterioration for Delta and White Fresco. Planting III



Shelf life - *Delta* and *White Fresco*

Figure 18 and Appendix V, Table 16, p.122.

Shelf-life performance of *Delta* grown hydroponically was good in the early stages post-production, but overall shelf life was comparable across all systems, Fig 18a.

The converse was true for *White Fresco* where soil grown stems appeared to have the advantage in the early stages of shelf-life but once again the overall shelf-life was comparable across all systems, Fig 18b.

Water Utilization

Appendix V, Table 17, p.123.

Comparison of water usage throughout the life of the crop indicated that the Probase system had the greatest uptake of water during the early stages of establishment and this was maintained throughout the crop cycle whereas the aeroponic system had a relatively low uptake of water from the system. In the latter stages of crop growth much more water was applied to the soil crop than to the hydroponic systems.

Nutrient analyses

Appendix V, Tables 18-23, pp.124-129.

Target pH and conductivity were reasonably well maintained throughout the life of the crop although the Probase system was difficult to stabilise with resultant high pH and low concentration of NO_3 and phosphate and variable levels of potassium. As observed for Planting II the iron, zinc and manganese levels in the Probase recirculating solution were lower than in the other solutions.

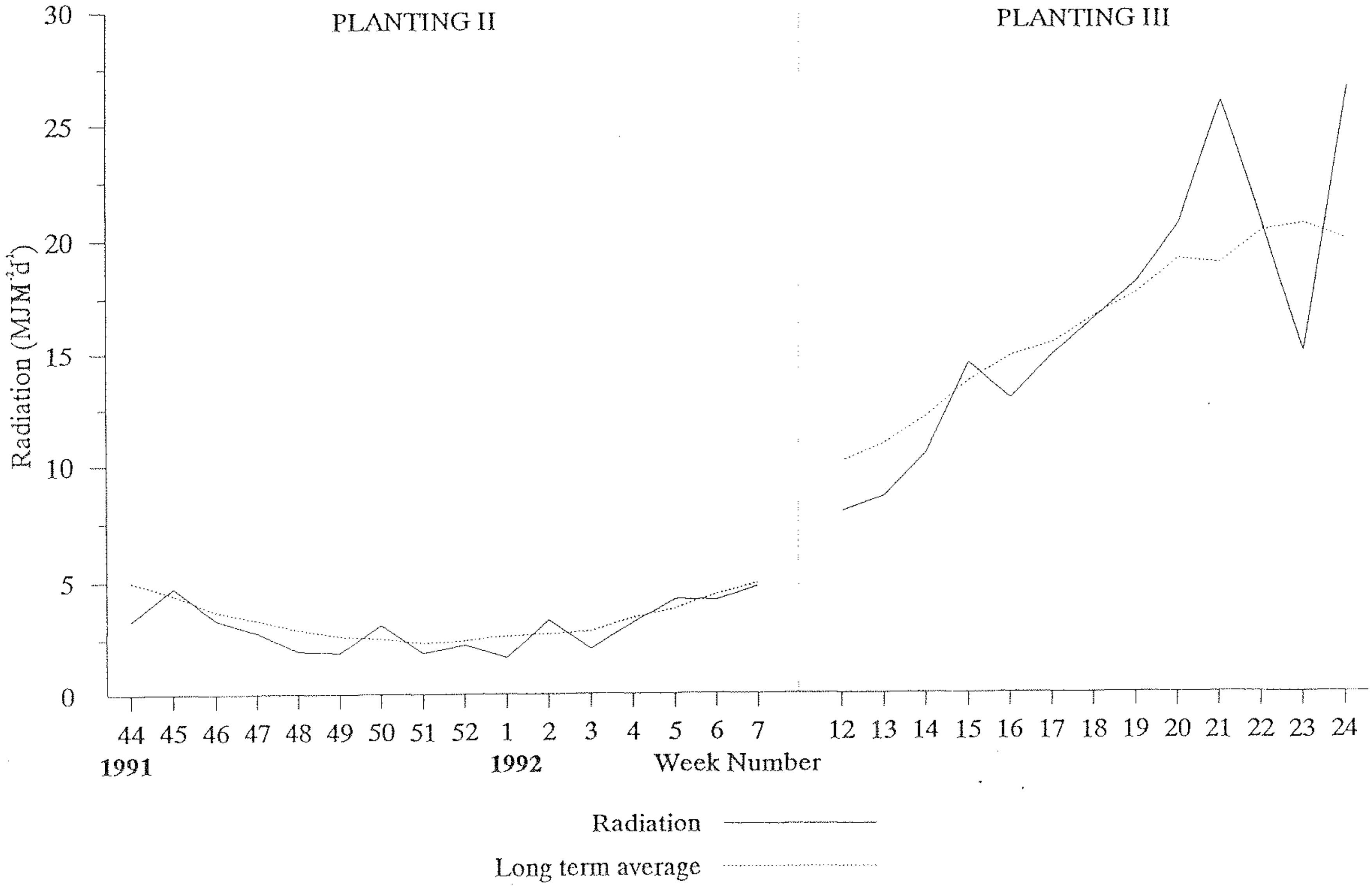
Leaf analyses

Appendix V, Tables 24-26, pp.130-132.

As observed for Planting II satisfactory levels of % N, % P, % K and % Mg were achieved throughout the life of the crop on the hydroponic and soil systems but as before the % Mn levels were higher for the soil grown plants than for the hydroponic sand and Probase crops.

Figure 19

Solar radiation measurements at HRI Efford during the periods of the trial



Environmental records

Solar radiation - Planting II and III

Figure 19, p.51.

Winter light levels were comparable with the long term average during the cropping period of Planting II and these figures were 3-5 times lower than the solar radiation measured during the cropping period of Planting III. Particularly high light levels were achieved approximately one month before harvest of Planting III.

Nutrient solution temperatures

Planting II

Temperatures of recirculating solutions during the trial period ranged on average between 16 and 17°C, ie. 1-2 degrees below ambient environmental conditions.

Planting III

In the early part of Planting II solution temperatures ranged between 16 and 18°C and during high light periods tank temperatures increased reaching up to 25°C once again reflecting ambient environmental conditions.

DISCUSSION

Although reasonable results were achieved on the aeroponic system, problems with crop establishment meant that the slow growth at the start of cultivation was not sufficiently compensated for by later development. The aeroponic system was improved by increasing the frequency of mist bursts, the 'English' as opposed to the dryer 'Dutch' regime, but still failed to reach the growth achieved in the soil or hydroponic systems. A greater check occurred with the Spring planting as might be expected with the higher temperatures at that time of year.

Jute plugs were only compared in the aeroponic system, and produced much poorer results than the peat blocks in respect of early establishment and growth.

Successful production of AYR chrysanthemums was achieved on hydroponic systems during both the winter and spring trial period (Plantings II and III). Hydroponic crops outperformed the soil grown crops on both occasions, with plants from these systems having longer and thicker stems with larger leaves than those from soil.

The 'hydroponically grown' winter crop was particularly responsive to the influence of interrupted lighting. This may have been in response to the enhanced availability of nutrients/water on these systems, without saturation, at a time when the soil grown crop was less frequency irrigated (owing to low light levels). Good 'take-off' by the hydroponic crops planted in the spring may have occurred for the same reasons i.e. readily available supply of nutrients and water for initial root growth without waterlogging. It appears therefore that the vegetative phase of growth was particularly enhanced by cultivation in hydroponic systems. This was also reflected by increase in leaf area of hydroponically grown crops.

Snowdon responded well to being grown hydroponically, especially where sand was used as the substrate (Planting II). These stems were not only longer but their increase in stem fresh weight reflected the overall improvement in thicker stems and larger leaves.

Benefits of hydroponic production were more pronounced with *Delta* which produced particularly good quality stems both on hydroponic sand and Probase systems during the winter period (Planting II). These again were superior to the soil grown crop. A similar pattern of results was achieved in the spring (Planting III), when once again hydroponically grown stems of *Delta* were longer, thicker and heavier than conventionally grown stems. Results for *White Fresco* (Planting III) were even more marked, since although there was only slight variation in crop height, the superior quality achieved on hydroponic systems was reflected by the notable increase in stem weight, particularly on sand.

Although it was initially envisaged that study of roots in hydroponic systems, especially in response to change from the long day to short day periods and interruptions would be easy, this was not found to be the case. Accurate assessment of root growth relative to the growing system was difficult, although the macro-variation between aeroponic and substrate-based root systems was marked. Relatively little root system was required to support the hydroponically grown crops, presumably because the movement of readily available nutrients and water down through the substrate meant that only a limited absorptive area was necessary.

The nutrient solution was adapted, with help from ADAS, from other NFT systems, and has produced excellent results. Whether further experiments in growth could be achieved by manipulation of nutrients applied, or whether the application was in the 'luxury' level with cost savings possible is the subject for further work.

No disease symptoms were seen in either the winter or spring trials even though some pathogenic organisms were isolated. The apparent decline in pathogenic activity as the crop matured may have been due to diminished root activity during maturation. Since no detrimental effects were observed following the successive planting (Planting III) of both substrate and soil based systems, it was concluded that pathogens were either present in the system at low inoculum levels, were only weakly pathogenic, or that root regeneration was adequate to compensate for any root loss due to pathogenic attack. It is reasonable to anticipate that pathogen build up would increase with each additional planting, and it will be important to monitor just how many crops can be grown before damage/poorer growth becomes apparent.

The possibility of optimizing irrigation and nutrition requirements of a hydroponically grown crop provides opportunity for manipulation of growth and potential to improve productivity. If these hydroponic systems can be developed to minimize disease risks, with minimal sterilisation and cultivation requirements, then the systems become increasing attractive and cost effective with the potential to develop further mechanisation with associated reduced labour costs.

CONCLUSIONS

This series of trials has clearly demonstrated the potential of hydroponic systems for AYR chrysanthemum production, both during the Winter and Spring. Three varieties were used. *Snowdon* for Winter cropping, *White Fresco* for Spring and *Delta* over both seasons. All responded in a similar manner, and the main points can be summarised as follows:

- Hydroponic crops established and grew away well, but difficulties were experienced in the aeroponic system, especially in jute plugs as opposed to peat blocks, which was reflected in their poorer final results.

- Root growth in hydroponic systems appeared slightly less than in soil, whilst that in the aeroponic system was considerably more.

- The nutrient solution developed for this work has produced good results.

- While disease pathogens were isolated from all systems, their presence did not appear to be adversely affecting growth at this stage. Successive plantings need monitoring to establish how many crops can be taken through without the need for sterilization.

RECOMMENDATIONS FOR FURTHER WORK

The successful production of AYR chrysanthemums achieved with the hydroponic systems at Efford has stimulated interest in developing these systems and in applying the experience to further improve conventional soil production as follows:

- Investigate the potential disease risk and number of crops which can be grown between substrate sterilizations.
- Examine potential control strategies in order to increase cropping intervals between sterilization.
- Investigate the threat of *Pythium*. Work at Naaldwijk has shown that *Pythium* can spread very easily in the nutrient solution.
- Examine the influence of Aaterra on the quality of conventionally grown soil crops ie. to see if Aaterra drenches post planting could enhance plant performance beyond that of plants which just had Aaterra incorporated in blocks.
- Determine the benefit, if any, of low pH. Work at Naaldwijk suggests that a low pH in the recirculating solution may suppress *Pythium*.
- Investigate the nutritional uptake and irrigation requirement relative to soil grown crops.
- Examine the depth of sand required, since this could significantly alter the economics of cropping.

This new programme of work will further examine the potential of hydroponic culture and its associated management.

APPENDICES

APPENDIX I

Interim Report for HDC, Planting I M J Leatherland

Introduction

As part of a long term trial on hydroponic systems for chrysanthemums, a screening trial was set up at Efford in April 1991 to examine a range of possibilities for growing chrysanthemums out of the soil.

Treatments

Two sets of treatments were applied relating either to the main substrate or to the propagation technique.

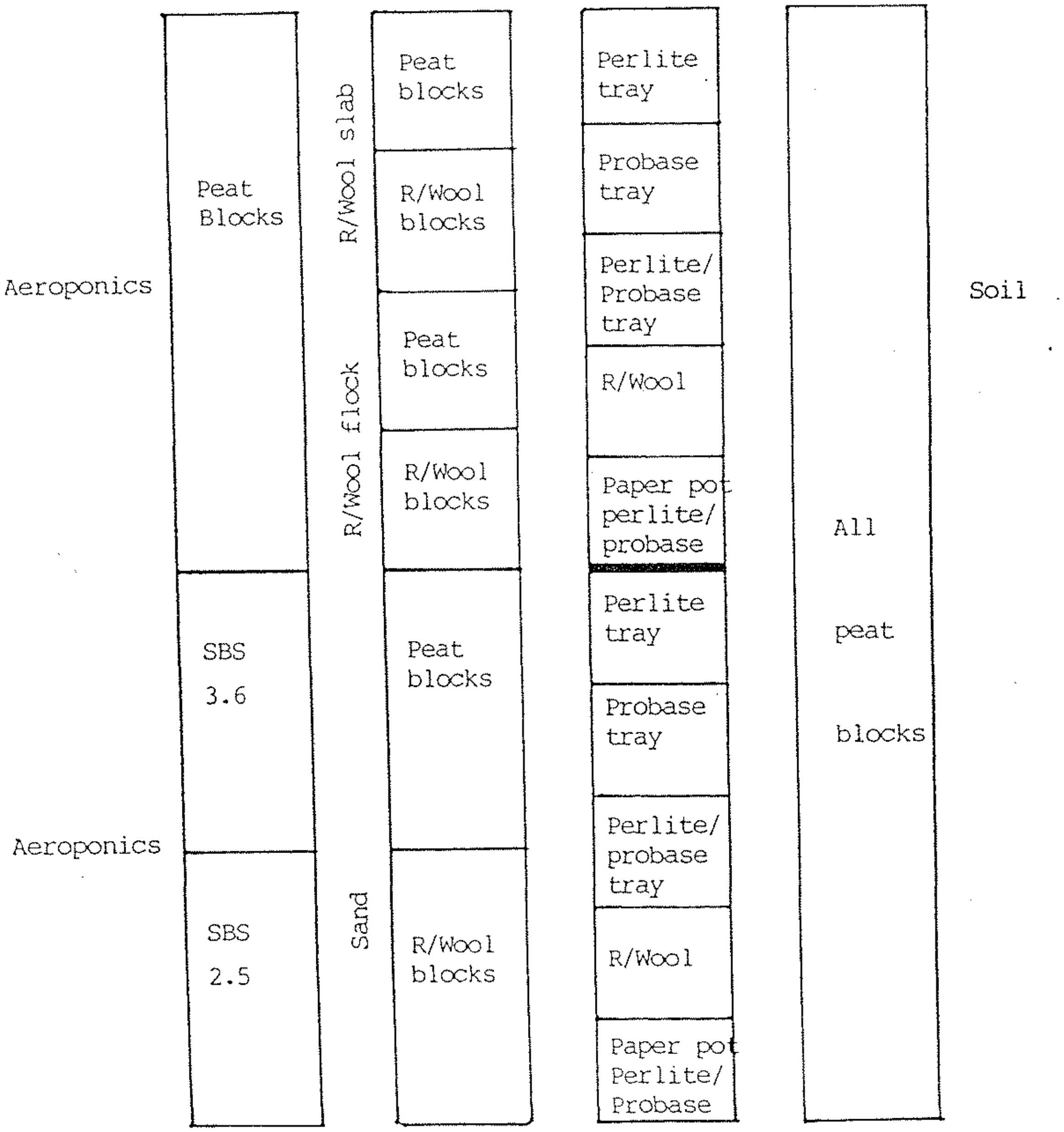
Main treatments

1. Soil
2. Perlite (standard horticultural grade)
3. Probase - a commercially available silicon based substrate
4. Rockwool slabs
5. Rockwool flock (medium)
6. Sand (Midhurst sharp sand). See Appendix II, p.70 for details of specification.
7. Aeroponics

There were two hydroponic media beds running on a common irrigation system fed from a below ground tank and dosed initially by hand and later by a Stapley control panel. There were also two aeroponic systems, each approximately half the size of the hydroponic beds. These were compared with a standard crop grown in the soil under normal commercial conditions.

Figure 1 Planting Plan for Hydroponics Trial

Spring 1991



Plants were placed at approximately 12 cm x 12 cm spacing.

Propagation treatments

Various techniques were employed depending on the final growing medium.

On Perlite:	1.	Japanese paper pots containing perlite and Probase fine 50:50
	2.	Rockwool blocks
	3.	Perlite and Probase fine in module tray
	4.	Probase fine in module tray
	5.	Perlite in module tray
On Probase:		Same range as for perlite
On Rockwool slabs:	1.	Rockwool blocks
	2.	4.3 cm peat blocks
On Rockwool flock:	1.	Rockwool blocks
	2.	4.3 cm peat blocks
On Aeroponics:	1.	4.3 cm peat blocks
	2.	2.5 cm Grodan SBS modules *
	3.	3.6 cm Grodan SBS modules *

* SBS - single block system. These modules were inserted through holes cut in the styrofoam lid so that the base of the module was as near to the base of the lid as possible. Peat blocks were sat above holes in the lid as to push them through was likely to cause disintegration of the block.

A full plan of the trial is given in Figure 1.

Cultural details

The same feed recipe was given to all hydroponic systems. Full details are given in Table 1. The feed was changed when the level of phosphate available in the solution dropped dramatically.

Table 1.
Feed recipes

	Planting (week 14) to week 21 g/litre stock	Week 21 to harvest g/litre stock
Potassium nitrate	43.4	43.4
Ammonium nitrate	10.0	10.0
Mono ammonium phosphate	5.7	7.0
Magnesium sulphate	36.0	36.0
EDTA	2.6	3.5
Manganese sulphate	0.3	0.3
Borax	0.09	0.09
Copper sulphate	0.01	0.01
Zinc sulphate	0.04	0.04
Ammonium molybdate	0.009	0.009
Acid (Nitric Acid, 60%)	100 ml/l	
E.C. target	2000 µS at 20°C	

Planting

Various planting techniques were used depending on the variables involved. All propagation modules were stood directly on the Probase due to its abrasive properties. The perlite and rockwool flock were planted into the medium and the sand and rockwool slabs were planted on top of the medium.

Planting date: 2 April

Short days started: 24 April

Irrigation

Watering was either through the aeroponic mist lines or through volmatic drip lines on the hydroponic beds. The aeroponic beds were watered for 10 seconds every minute and the other hydroponic beds for 1 minute every 6 minutes.

Results

A sample taken on 6 May is given below as a typical example of the nutrient levels. Conductivity was around 1500 μS and pH at 7.0 during the life of the crop. There is no doubt that the pH should have been lower (5.5-6.0) and problems with the dosing system were subsequently rectified. This may have been at least partially to blame for the yellowing of foliage typical of iron deficiency seen shortly after the start of short days, but it is a problem which has been seen a number of times before in hydroponically grown crops.

Hydroponic sample on 6 May: mg/l

pH	**EC**	**NH_4N**	**NO_3-N**
6.7	1380	1.0	121

P	**K**	**Ca**	**Mg**	**Cu**	**Na**	**Fe**	**Mn**	**Zinc**	**B**
3	96	171	13	0.22	42	0.89	0.1	1.98	0.21

Establishment of plants

Hydroponic systems require a greater degree of post planting care than conventional plants until roots have had a chance to acclimatise to unfamiliar growing circumstances. The most difficult to establish were the aeroponic systems, particularly in peat blocks where roots took some time to find their way into the mist under the styrofoam.

The coarse Probase material also caused some difficulties with establishment as drainage was very good and it was not practical to plant the cuttings into the material.

Root measurements

Sample plants were removed from the aeroponics systems during the start of short days and total root length was measured from the base of the block to the end of the longest root. These are shown in Table 2 and show a slower growth in peat block plants with *Snowdon*. This is a little at variance with the visual observations at the time which suggested that the peat block plants developed better with less chlorosis in the two weeks after start of short days.

Table 2. Length of root (cm) in aeroponics

Treatment	1 Day before S.D.	2 Days after S.D.	5 Days after S.D.	7 Days after S.D.	9 Days after S.D.	12 Days after S.D.	14 Days after S.D.	16 Days after S.D.
Rockwool 3.6 modules								
Delta	-	16.6	14.7	19.3	22.4	27.4	26.4	29.9
Snowdon	5.3	16.1	18.3	22.1	24.5	26.1	29.2	30.7
Peat blocks								
Delta	-	21.5	21.5	21.0	22.8	26.1	31.0	27.1
Snowdon	11.5	11.3	14.6	15.7	15.2	17.9	18.8	18.2

Plant height

Weekly measurements of plant height were made beginning shortly after the start of short days and again at harvest. Results at harvest are shown in Table 3.

Table 3. Height at harvest (cm)

	Delta		*Snowdon*	
Treatment Main/Prop.	**Height**	**Variance**	**Height**	**Variance**
Aeroponics/Rockwool 2.5	67.9	35.5	61.7	27.8
Aeroponics/Rockwool 3.6	82.0	54.3	67.0	82.4
Aeroponics/peat	87.4	33.3	102.6	33.2
Sand/Rockwool	96.9	4.4	113.8	25.0
Sand/Peat	98.1	5.1	122.2	17.5
Rockwool granules/Rockwool	102.0	15.6	114.7	4.3
Rockwool granules/peat	100.2	14.0	123.9	27.9
Rockwool slabs/Rockwool	87.7	81.8	90.6	112.6
Rockwool slabs/Peat	100.7	13.6	117.6	27.5
Probase/Probase paper pots	70.4	47.1	85.1	95.8
Probase/Rockwool	79.4	58.5	90.5	61.5
Probase/Probase in tray + Perlite	86.9	12.7	105.1	46.0
Probase/Probase in tray	90.2	23.4	102.9	60.6
Probase/Perlite in tray	91.3	10.6	102.0	41.4
Perlite/Probase + Perlite in paper pot	87.8	38.9	102.1	39.7
Perlite/Rockwool	89.1	39.8	106.5	22.0
Perlite/Probase + Perlite in Tray	94.2	28.3	105.5	70.2
Perlite/Probase in Tray	95.7	28.0	105.2	23.5
Perlite/Perlite in Tray	91.9	11.4	100.6	33.4
Soil/Peat Block	87.3	0.9	107.5	15.0

The variation in height between treatments was considerable. The aeroponics treatments were the shortest for both propagation methods. This reflects the slow establishment. Differences in average height between the other treatments were less pronounced but there was variation between the plants in a plot as shown by the variance figure. The larger the figure, the more uneven the stand. The most uniform was *Delta* in the soil with practically no height variation, the most variable was the rockwool on rockwool slab treatment. There were, however, few consistent trends amongst the other treatments with variance ranging from 0.9 to 112. Of the hydroponic treatments the sand provided the most uniform stand closely followed by the rockwool granules.

Disease

There were no visible signs of disease until about 4 weeks before harvest when black decaying roots were found in the aeroponics system which subsequently spread to almost all plants leading to a very poor grade-out. This was diagnosed as *Pythium*. *Pythium* was also found to a lesser extent in the other hydroponic systems at harvest but was not severe enough to cause any wilting.

Grade-out

The final grade-out figures are shown in Table 4. The aeroponics figures are slightly higher than appearance at the time may have suggested. This was because an estimate was made of what grade stems would have been had they not suffered from *Pythium*. The best consistent grade-outs came from the sand treatment. Other results were very variable and it is difficult to detect consistent trends.

Short days

The number of short days to harvest did not vary greatly. These are also shown in Table 4. There were hopes that the hydroponic systems would flower earlier than those in the soil but this did not prove to be the case.

Weights

The weight of stems cut off at the base, level with the top of the peat block, at harvest gives an indication of the amount of growth made. Fresh and dry weights as an average of 20 cut stems are given in Table 5. As with other recorded parameters the weights were very variable and not particularly consistent. The soil treatment did however produce the best results on average for both varieties.

Table 4. Final grade-out in wraps/1000 stems and number of short days to flower

	Delta		*Snowdon*	
Treatment Main/Prop.	**Wraps**	**S.D.**	**Wraps**	**S.D.**
Aeroponics/Rockwool 2.5	65	55	45	60
Aeroponics/Rockwool 3.6	77	55	42	59
Aeroponics/peat	52	54	69	58
Sand/Rockwool	74	55	70	58
Sand/Peat	69	57	68	59
Rockwool granules/Rockwool	53	57	69	57
Rockwool granules/peat	60	57	79	62
Rockwool slabs/Rockwool	61	55	32	62
Rockwool slabs/Peat	63	55	73	58
Probase/Probase paper pots	58	57	59	60
Probase/Rockwool	53	58	65	61
Probase/Probase in tray + Perlite	56	57	71	59
Probase/Probase in tray	62	56	71	59
Probase/Perlite in tray	66	56	74	59
Perlite/Probase + Perlite in paper pot	56	56	67	60
Perlite/Rockwool	63	56	69	59
Perlite/Probase + Perlite in Tray	63	57	72	60
Perlite/Probase in Tray	69	56	73	59
Perlite/Perlite in Tray	69	56	63	59
Soil/Peat Block	66	58	65	59

Table 5. Fresh and dry weight/plant at harvest (g)

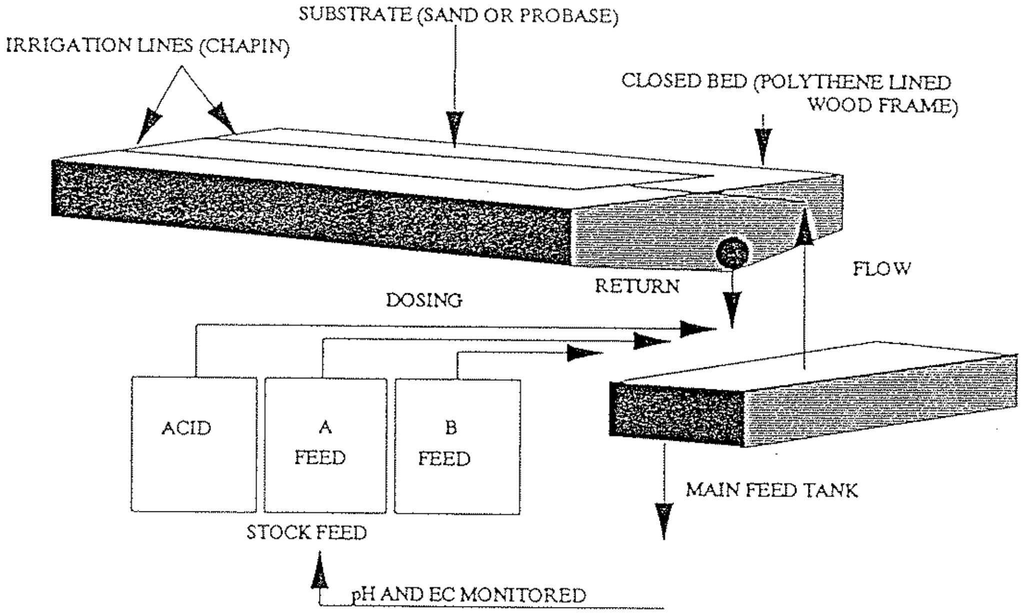
Treatment Main/Prop.	*Delta* Fresh	*Delta* Dry	*Snowdon* Fresh	*Snowdon* Dry
Aeroponics/Rockwool 2.5	81	11.5	112	14.0
Aeroponics/Rockwool 3.6	97	14.5	133	18.5
Aeroponics/peat	70	14.0	124	12.0
Sand/Rockwool	113	14.5	135	20.5
Sand/Peat	115	11.0	133	21.5
Rockwool granules/Rockwool	90	13.5	135	20.5
Rockwool granules/peat	91	15.0	153	29.0
Rockwool slabs/Rockwool	82	11.0	101	15.0
Rockwool slabs/Peat	96	17.0	141	23.5
Probase/Probase paper pots	94	21.0	121	19.5
Probase/Rockwool	76	15.5	124	14.5
Probase/Probase in tray + Perlite	85	13.0	135	19.0
Probase/Probase in tray	92	13.5	144	21.0
Probase/Perlite in tray	97	24.0	108	16.0
Perlite/Probase + Perlite in paper pot	94	14.5	113	14.0
Perlite/Rockwool	94	14.5	128	19.0
Perlite/Probase + Perlite in Tray	105	16.5	132	17.0
Perlite/Probase in Tray	95	14.5	148	21.0
Perlite/Perlite in Tray	103	15.5	134	20.0
Soil/Peat Block	125	20.0	147	35.0

Conclusion

This work was set up as a preliminary screening trial to assess the potential of aeroponic and hydroponic systems for the production of AYR chrysanthemums. While results were rather variable it was shown that with attention to detail during establishment and close control of nutrition and disease crops could be successfully produced in a range of substrates, and particularly hydroponic sand. The information gained from this work will form the basis for setting up the main trial, planned for a Winter and Spring planting.

Appendix II

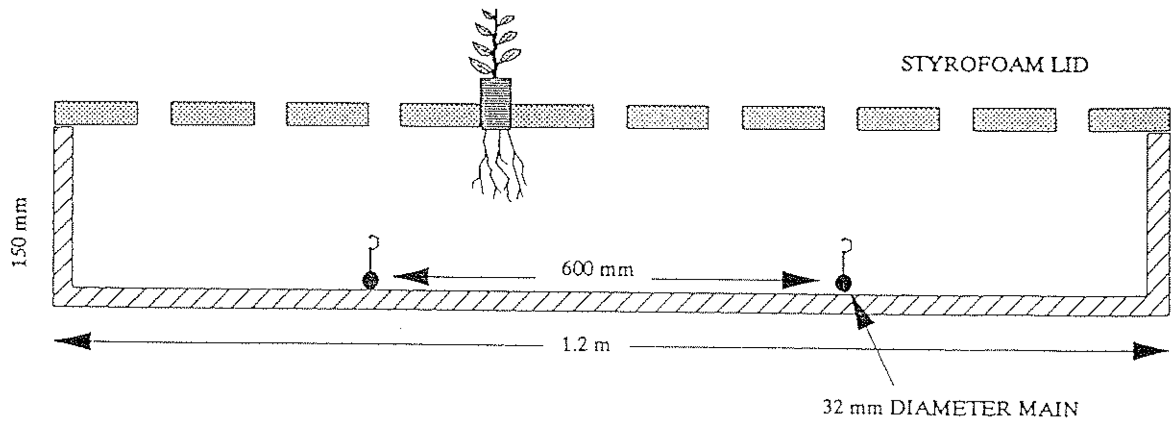
i) DIAGRAM OF HYDROPONIC BED



Sand specification:	Sharp - lime free with suitable range of particle sizes as follows:	
	4.0 - 0.5 mm	30 - 45 per cent by weight
	0.5 - 0.2 mm	40 - 60 per cent by weight
	0.2 - 0.02 mm	5 - 15 per cent by weight

Irrigation frequency:	Probase -	4 min pulse	3 min pause	24 hr continuous cycle
	Sand -	2 min pulse	3 min pause	24 hr continuous cycle

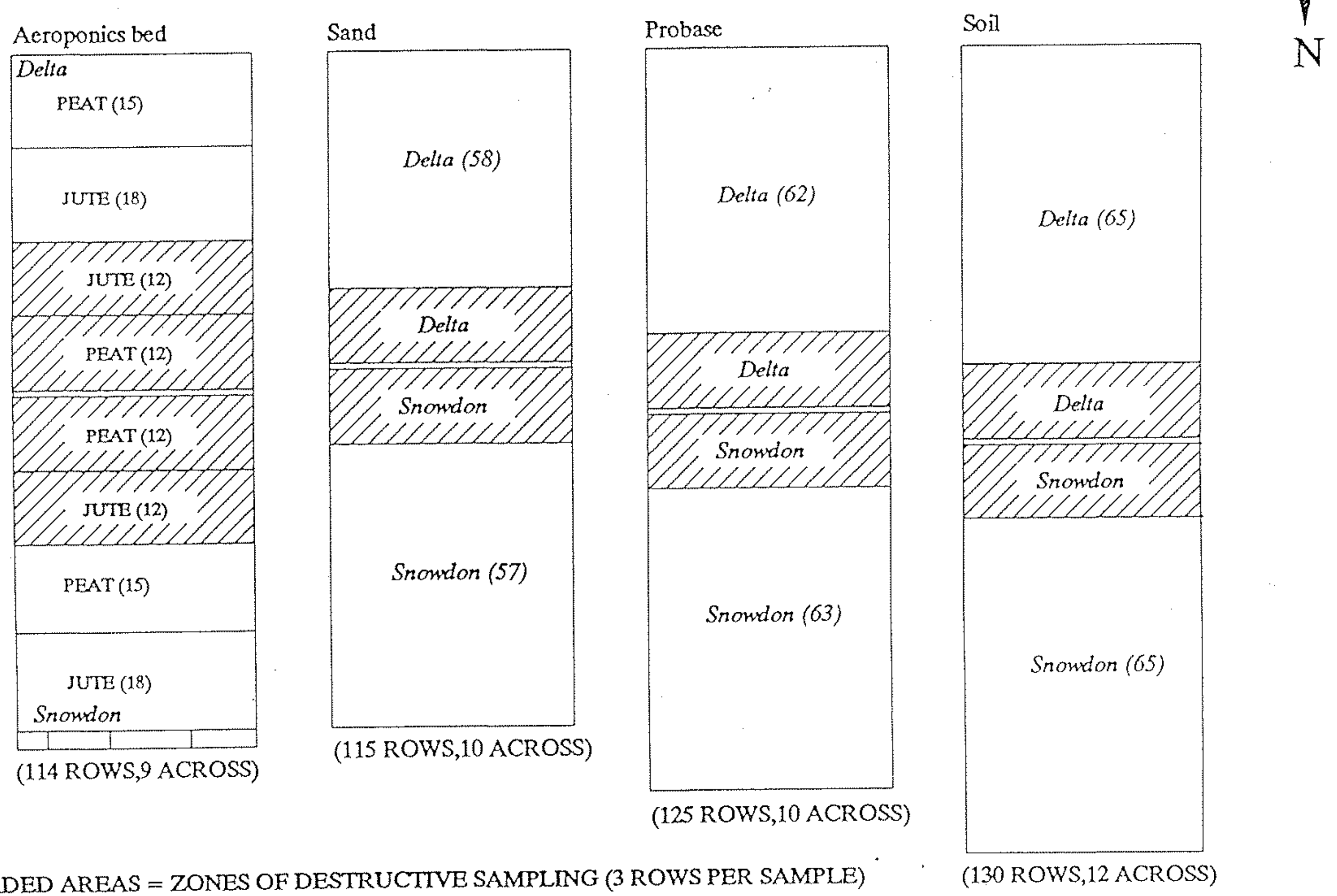
ii) DIAGRAM OF AEROPONIC BED



Irrigation frequency:	See Materials and Methods p.4.	
	Planting II	= 'English' frequency,
	Planting III	= 'Dutch' and 'English' frequency.

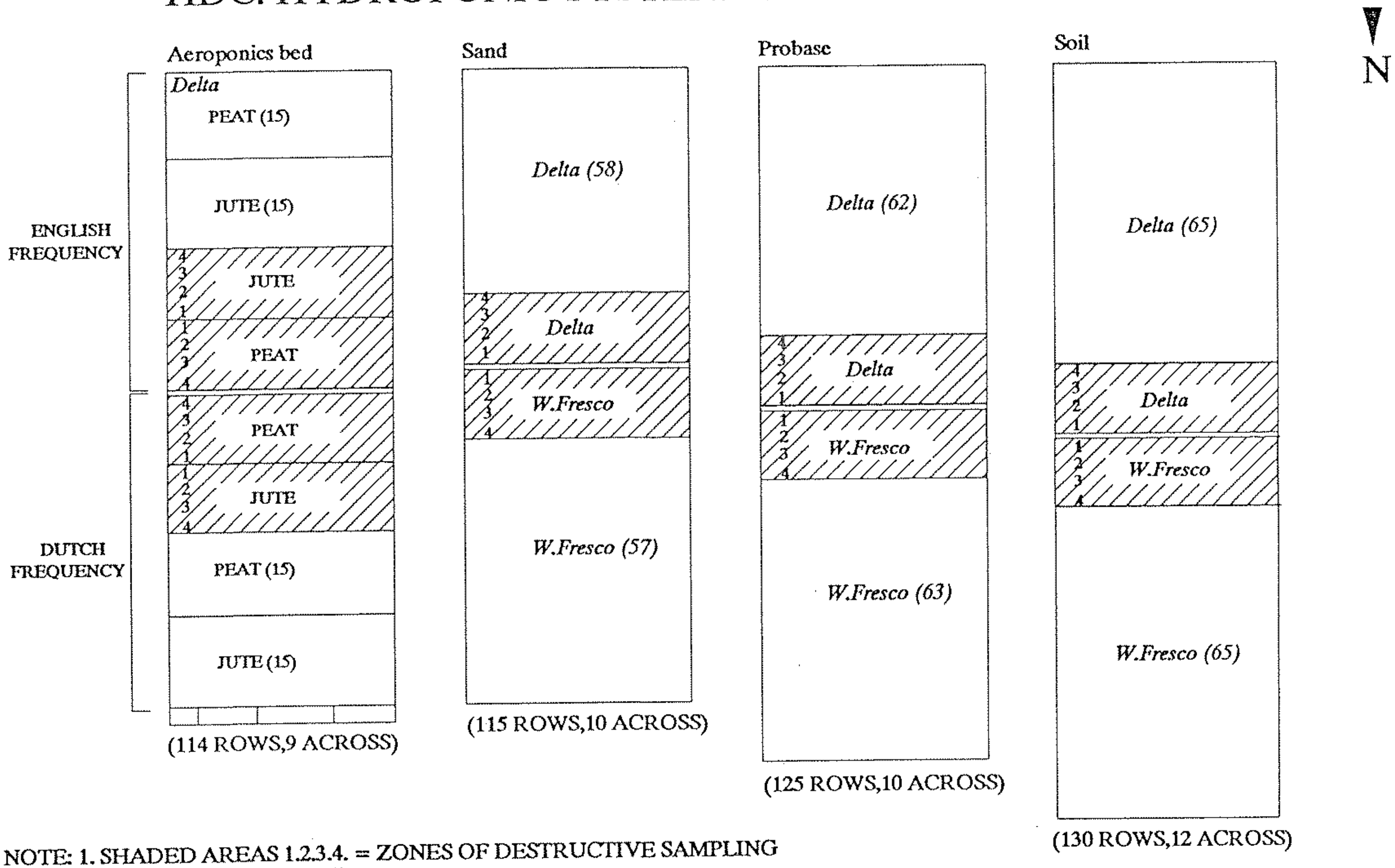
Appendix II

HDC: HYDROPONIC SYSTEMS PLANTING II



NOTE: 1. SHADED AREAS = ZONES OF DESTRUCTIVE SAMPLING (3 ROWS PER SAMPLE)
2. FIGURES IN BRACKETS = NO OF ROWS PER ZONE, 85% PLANT DENSITY
(ALTERNATIVE PLANTS ONLY EVERY THIRD ROW)

HDC: HYDROPONIC SYSTEMS PLANTING III



NOTE: 1. SHADED AREAS 1.2.3.4. = ZONES OF DESTRUCTIVE SAMPLING
(3 ROWS PER SAMPLE)
2. FIGURES IN BRACKETS = NO OF ROWS PER ZONE, 100% PLANT DENSITY.

Appendix III

Hydroponic system

Aeroponic, Probase and sand systems - Target Nutrient Concentrations in Feed Plantings II and III

	Diluted Feed (mg/litre)	Recirculated Solution Target range mg/litre
NO_3-N	150	125-175
NH_4-N	7	< 1
P	35	25-35
K	250	200-300
Mg	30	25-40
Ca	125	125-200
Fe	3.0	2-3
Mn	1.0	0.5
Cu	0.1	0.1
Zn	0.2	0.2
B	0.3	0.3
Mo	0.05	0.05

Appendix III

Feed recipe

Conductivity		1600 μS at 20°C
		1750 μS at 25°C
Acid Tank	(100 litres)	
	Nitric acid (60%)	7 litres
A Tank	(100 litres)	
	Calcium nitrate (Norsk)	3.5 kg
	Potassium nitrate	3.2 kg
	Fe EDTA (13% Fe)	350 g
B Tank	(100 litres)	
	Potassium nitrate	3.0 kg
	Potassium sulphate	1.5 kg
	Magnesium sulphate	4.5 kg
	Ammonium nitrate	330 g
	Monopotassium phosphate (KH_2PO_4)	2.3 kg
	Manganese sulphate (28% Mn)	50 g
	Copper sulphate	6 g
	Zinc sulphate	15 g
	Borax	40 g
	Ammonium molybdate	1.5 g
Approximate Dilution Rate		1:150

Appendix III

Soil system

Planting II

Standard winter feed programme of 150N : 200 K_2O
Stock tank (100 litres)

Potassium nitrate	8.7 kg
Ammonium nitrate	5.3 kg

Approximate dilution rate 1 : 200

Planting III

Standard summer feed programme of 225 N : 175 K_2O
Stock tank (100 litres)

Potassium nitrate	7.7 kg
Ammonium nitrate	9.9 kg

Approximate dilution rate 1 : 200

Frequency of application is adjusted according to system and crop requirements.

APPENDIX IV

Table 1. Systems comparison of plant height (cm) of *Delta* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Plant height (cm) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	19.2 [a]	28.5	29.0	28.7	28.4
2.	25.2	35.2	35.6	38.6	36.5
3.	31.9	42.2	45.1	45.8	44.4
4.	42.3	49.8	60.9	62.7	56.8
5.	72.7	72.4	86.9	88.1	81.5

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 20 replicate plants per treatment.

APPENDIX IV

Table 2. Systems comparison of plant height (cm) of *Snowdon* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Plant height (cm) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	26.3 [a]	33.2	35.9	40.1	38.8
2.	35.7	41.9	43.5	48.1	49.4
3.	44.9	50.9	54.2	58.2	53.8
4.	57.7	62.9	66.5	74.9	64.5
5.	78.4	93.6	92.4	97.6	92.2

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 20 replicate plants per treatment.

APPENDIX IV

**Table 3. Systems comparison of stem fresh weight (g) of *Delta* at key stages throughout the life of the crop.
Planting II.**

Assessment Stage	Stem fresh weight (g) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	8.6 [a]	13.6	14.7	14.1	13.7
2.	9.6	15.3	17.7	20.0	19.8
3.	15.2	19.9	26.2	33.7	26.2
4.	24.1	22.9	36.3	34.4	28.9
5.	63.6	40.6	66.3	65.1	56.5

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 15 replicate plants per treatment.

APPENDIX IV

Table 4. Systems comparison of stem fresh weight (g) of *Snowdon* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Strem fresh weight (g) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	9.0 [a]	13.6	14.9	17.5	15.9
2.	14.1	15.6	19.6	23.7	22.0
3.	21.6	24.2	29.3	36.4	26.0
4.	28.5	27.1	37.6	39.8	38.9
5.	70.2	80.9	72.8	89.4	74.6

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 15 replicate plants per treatment.

APPENDIX IV

Table 5. Systems comparison of stem dry weight (g) of *Delta* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Stem dry weight (g) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	1.0 [a]	1.4	1.3	1.2	1.2
2.	1.1	1.7	1.5	1.8	1.5
3.	1.6	2.3	2.3	2.9	2.1
4.	2.5	3.0	3.0	3.0	2.5
5.	7.2	5.9	7.5	8.3	6.2

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 15 replicate plants per treatment.

APPENDIX IV

Table 6. Systems comparison of stem dry weight (cm) of *Snowdon* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Plant height (cm) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	1.0 [a]	1.4	1.4	1.6	1.4
2.	1.4	1.9	1.6	2.2	2.1
3.	2.4	3.0	2.5	3.5	2.6
4.	3.3	3.7	3.8	4.2	3.3
5.	8.3	11.5	8.5	10.7	8.5

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 15 replicate plants per treatment.

APPENDIX IV

Table 7. Systems comparison of root length (cm) of *Delta* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Root length (cm) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	13.9 [a]	11.0	8.6	7.9	10.2
2.	12.3	8.8	7.1	7.2	10.3
3.	14.0	9.3	9.3	12.4	9.8
4.	14.3	9.4	9.7	11.0	9.7
5.	35.2	29.5	13.9	17.9	11.8

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 20 replicate plants per treatment.

APPENDIX IV

Table 8. Systems comparison of root length (cm) of *Snowdon* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Root length (cm) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	18.7 [a]	12.4	7.3	8.2	8.4
2.	21.0	13.9	5.6	6.3	6.1
3.	26.5	18.4	7.1	9.1	8.7
4.	26.2	13.8	7.8	9.8	8.9
5.	37.8	32.1	13.9	16.0	11.6

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 20 replicate plants per treatment.

APPENDIX IV

Table 9. Systems comparison of root fresh weight (g) of *Delta* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Root fresh weight (g) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	0.8 [a]	0.4	0.7	0.5	1.1
2.	0.8	0.3	1.0	0.6	1.1
3.	1.7	1.3	2.4	2.8	2.5
4.	2.4	0.3	1.9	1.4	0.7
5.	9.1	4.0	4.9	3.2	1.6

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 15 replicate plants per treatment.

APPENDIX IV

Table 10. **Systems comparison of root fresh weight (g) of *Snowdon* at key stages throughout the life of the crop. Planting II.**

Assessment Stage	Root fresh weight (g) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	1.3 [a]	0.5	0.3	0.5	0.4
2.	2.0	0.4	0.3	1.1	0.3
3.	5.1	2.4	1.3	1.3	1.7
4.	5.1	0.8	0.8	0.8	0.3
5.	9.4	8.6	2.4	2.6	1.4

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 15 replicate plants per treatment.

APPENDIX IV

Table 11. Systems comparison of root dry weight (g) of *Delta* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Root dry weight (g) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	0.05 [a]	0.06	0.19	0.17	0.08
2.	0.05	0.03	0.20	0.05	0.09
3.	0.11	0.18	0.40	0.28	0.40
4.	0.15	0.03	0.37	0.09	0.08
5.	0.62	0.34	0.51	0.28	0.58

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 15 replicate plants per treatment.

APPENDIX IV

Table 12. Systems comparison of root dry weight (g) of *Snowdon* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Root dry weight (g) relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	0.07 [a]	0.04	0.07	0.06	0.07
2.	0.11	0.04	0.05	0.11	0.04
3.	0.32	0.25	0.23	0.13	0.31
4.	0.30	0.07	0.08	0.07	0.04
5.	0.75	0.73	0.24	0.26	0.45

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean of 15 replicate plants per treatment.

APPENDIX IV

Table 13. Root discoloration of *Delta* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Percentage root area discoloured relative to system (and propagation media)					
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	3.0 [a]	0.4	1.0	0.8	0.6
2.	7.0	1.4	1.6	0.4	0.8
3.	-	-	-	-	-
4.	100	5.6	41.0	5.2	17.4
5.	-	-	-	-	-

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean percentage root area discoloration from five plant root systems.

\- = Results not available.

APPENDIX IV

Table 14. Root discoloration of *Snowdon* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Percentage root area discoloured relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	- [a]	1.0	1.6	2.6	1.0
2.	2.2	1.6	1.0	1.0	1.2
3.	-	-	-	-	-
4.	100	12.4	20.0	14.6	52.0
5.	-	-	-	-	-

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Mean percentage root area discoloration from five plant root systems.

\- = Results not available.

APPENDIX IV

Table 15. Root disease assessments of *Delta* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Percentage of plants showing *Pythium* type growth relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	100 [a]	20	100	0	20
2.	100	100	80	80	80
3.	0	60	80	20	0
4.	100	60	80	20	20
5.	-	-	-	-	-

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Percentage recovery from direct plating of 5 root sections from 5 replicate plants sampled per treatment.

\- = Results not available.

APPENDIX IV

Table 16. Root disease assessments of *Snowdon* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Percentage of plants showing *Pythium* type growth relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
1.	-	100	20	20	0
2.	100	100	0	100	0
3.	20	0	20	20	0
4.	0	20	20	0	100
5.	-	-	-	-	-

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Percentage recovery from direct plating of 5 root sections from 5 replicate plants sampled per treatment.

\- = Results not available.

APPENDIX IV

Table 17. Recovery of pathogens from incubated roots of *Delta* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Percentage of roots showing fungal growth ((a) identified as *Pythium* (b) unidentified) relative to system (and propagation media)									
	Aeroponic				Hydroponic - Probase		Hydroponic - Sand		Soil	
	(Jute)		(Peat)		(Peat)		(Peat)		(Peat)	
1.	40 [a]	(100) [b]	20	(100)	0	(80)	20	(60)	0	(80)
2.	0	(100)	40	(100)	0	(100)	0	(80)	0	(40)
3.	20	(80)	0	(100)	0	(80)	0	(100)	0	(40)
4.	0	(60)	0	(40)	0	(100)	0	(100)	0	(100)
5.	-	-	-	-	-	-	-	-	-	-

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Percentage of roots showing *Pythium*, floats of 5 x 1 cm root sections from each of 5 plants.

[b] = Percentage of roots showing unidentified pathogen, floats of 5 x 1 cm root sections from each of 5 plants.

- = Results not available.

APPENDIX IV

Table 18. Recovery of pathogens from incubated roots of *Snowdon* at key stages throughout the life of the crop. Planting II.

Assessment Stage	Percentage of roots showing fungal growth ((a) identified as *Pythium* (b) unidentified) relative to system (and propagation media)											
	Aeroponic				Hydroponic - Probase		Hydroponic - Sand		Soil	
	(Jute)		(Peat)		(Peat)		(Peat)		(Peat)	
1.	- [a]	- [b]	80	(20)	20	(80)	60	(100)	0	(80)
2.	0	(100)	40	(80)	0	(100)	0	(80)	0	(20)
3.	0	(60)	0	(40)	0	(100)	0	(40)	0	(40)
4.	0	(100)	0	(20)	0	(100)	0	(100)	0	(100)
5.	-	-	-	-	-	-	-	-	-	-

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.92

[a] = Percentage of roots showing *Pythium*, floats of 5 x 1 cm root sections from each of 5 plants.

[b] = Percentage of roots showing unidentified pathogen, floats of 5 x 1 cm root sections from each of 5 plants.

- = Results not available.

APPENDIX IV

Table 19. Systems comparison of grade-out at harvest and total crop duration, *Delta* and *Snowdon*, Planting II.

Assessment Stage	Grade-out (wraps per 1000 stems planted[a]) and total crop duration (days) relative to system				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
Delta					
Wraps per 1000 stems	45.2	32.3	50.5	49.7	47.0
Crop duration	102.9	106.3	103.6	103.1	104.1
Snowdon					
Wraps per 1000 stems	46.2	47.8	49.6	49.1	45.4
Crop duration	106.3	104.9	107.2	106.0	106.3

[a] = Note that this Grade-out is not directly comparable with current commercial specification. It refers to the sum of total stems in each grade category (10, 13, 16, 19, 22, 25), each total divided by its respective grade (10, 13, etc), and the sum then divided by total number of stems cut (including waste).

APPENDIX IV

Table 20. Effect of production system on shelf-life of *Delta* and *Snowdon*. Planting II.

Assessment Stage	Number of days taken to deteriorate from shelf-life stage 1 to stage 2 and stage 2 to stage 3 relative to system (and propagation media)				
	Aeroponic		Hydroponic - Probase	Hydroponic - Sand	Soil
	(Jute)	(Peat)	(Peat)	(Peat)	(Peat)
Delta					
1 → 2	10.0 [a]	10.0	26.0	21.0	14.6
2 → 3	14.0	13.4	8.0	11.2	24.2
Total	24.0 [b]	23.4	34.0	32.2	38.8
Snowdon					
1 → 2	12.8	13.4	13.0	13.2	16.4
2 → 3	7.6	7.6	4.6	7.4	4.2
Total	20.4	21.0	17.6	20.6	20.6

[a] = Mean number of days taken to deteriorate, 5 stems per treatment

Stage 1 = fully expanded flowers

Stage 2 = partial deterioration

Stage 3 = complete deterioration

[b] = Total time taken to deteriorate completely

APPENDIX IV

Table 21. Statistical systems comparison of plant height (cm) of *Delta* and *Snowdon* combined at key stages throughout the life of the crop. Planting II.

Assessment stage	Average combined plant height (cm) of *Delta* and *Snowdon* relative to system (and propagation media)				Significant difference
	Aeroponic (Jute + Peat)	Hydroponic - Probase (Peat)	Hydroponic - Sand (Peat)	Soil (Peat)	
1.	26.6	32.4	34.4	33.6	N.S.
2.	34.8	39.6	43.4	43.0	N.S.
3.	42.2	49.6	52.0	49.1	N.S.
4.	53.9	63.7	68.8	59.7	N.S.
5.	79.3	89.6	92.8	86.8	N.S.

Assessment stage:

1.	Two days before start of short days	27.11.91
2.	One week after start of short days	06.12.91
3.	At start of interruption	18.12.91
4.	At end of interruption	28.12.91
5.	At harvest	13.02.91

Note: Owing to variability within plots, and small sample size, no significant difference between treatments could be identified.

APPENDIX IV

Table 22. **Analysis of Feed Solutions**
Aeroponics
Planting II

			Nutrient Concentration (mg/l)			
Date	**pH**	**μS at 20°C**	**NO_3**	**NH_4**	**P**	**K**
4.11.91	5.6	2720	294	14	27	429
11.11.91	5.8	3010	296	15	52	551
18.11.91	5.7	2660	259	13	39	426
25.11.91	5.2	2670	244	12	41	506
2.12.91	6.6	2580	218	12	55	451
9.12.91	6.6	2460	218	11	54	413
16.12.91	6.8	1930	162	6	42	347
30.12.91	6.5	1990	175	7	34	282
6.1.92	6.8	1830	170	7	36	280
13.1.92	6.7	1980	164	5	35	340
20.1.92	6.7	1860	165	3	41	299
27.1.92	6.7	2060	169	<1	41	305
3.2.92	6.6	1810	147	2	33	186
10.2.92	6.4	2000	153	3	47	307
17.2.92	6.4	1760	145	2	44	268

Targets:

pH	5.5 - 5.8
μS	1600 μS at 20°C, 1750 μS at 25°C
NO_3	125 - 175
NH_4	<1
P	25 - 35
K	200 - 300

APPENDIX IV

Table 23. **Analysis of Feed Solutions**
Sand
Planting II

Date	pH	μS at 20°C	Nutrient Concentration (mg/l) NO$_3$	NH$_4$	P	K
4.11.91	4.4	1510	127	4	6	137
11.11.91	5.8	1790	171	6	12	226
18.11.91	5.4	1780	165	5	13	180
25.11.91	6.2	2230	187	8	25	379
2.12.91	6.3	2230	171	8	39	360
9.12.91	6.7	2000	164	6	36	323
16.12.91	5.9	2140	165	4	47	370
30.12.91	5.8	1970	154	2	38	298
6.1.92	6.3	1780	155	<1	43	291
13.1.92	6.4	1890	156	<1	36	325
20.1.92	6.3	1800	146	3	44	301
27.1.92	7.0	1720	99	1	54	284
3.2.92	6.7	2350	142	7	86	494
10.2.92	6.5	1700	93	4	95	325
17.2.92	6.8	1260	80	3	39	191

Targets:

pH 5.5 - 5.8
μS 1600 μS at 20°C, 1750 μS at 25°C
NO$_3$ 125 - 175
NH$_4$ <1
P 25 - 35
K 200 - 300

APPENDIX IV

Table 24. Analysis of Feed Solutions

Probase

Planting II

			Nutrient Concentration (mg/l)			
Date	**pH**	**μS at 20°C**	**NO_3**	**NH_4**	**P**	**K**
4.11.91	5.7	1360	123	2	2	71
11.11.91	4.8	1840	205	5	7	190
18.11.91	5.3	1860	205	5	8	162
25.11.91	5.1	2120	209	8	15	313
2.12.91	6.0	1930	194	5	12	202
9.12.91	6.3	2010	217	5	14	232
16.12.91	6.5	1870	203	2	12	197
30.12.91	6.2	1460	154	<1	5	79
6.1.92	5.2	1320	155	<1	3	5
13.1.92	3.5	1580	163	<1	3	64
20.1.92	6.5	1290	144	<1	3	46
27.1.92	5.1	1420	160	<1	2	60
3.2.92	6.6	970	88	<1	6	62
10.2.92	6.8	1080	80	2	19	104
17.2.92	2.9	1360	101	<1	3	36

Targets:

pH	5.5 - 5.8
μS	1600 μS at 20°C, 1750 μS at 25°C
NO_3	125 - 175
NH_4	<1
P	25 - 35
K	200 - 300

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Table 25. **Analysis of Nutrient Concentration in Feed Solutions**
Aeroponics
Planting II

	Nutrient Concentration (mg/l)							
Date	**Ca**	**Mg**	**Fe**	**Zn**	**Mn**	**Cu**	**B**	**Na**
4.11.91	253	32	8.23	0.59	0.83	0.11	0.30	23
11.11.91	249	63	7.33	0.81	1.62	0.18	0.50	23
18.11.91	208	49	5.77	0.70	1.33	0.16	0.39	21
25.11.91	225	60	6.25	0.64	1.47	0.22	0.44	23
2.12.91	215	57	5.79	0.74	1.57	0.20	0.46	22
9.12.91	183	51	4.66	0.64	1.32	0.14	0.34	20
16.12.91	196	45	4.37	0.77	1.29	0.12	0.33	23
30.12.91	163	32	4.21	0.72	0.91	0.13	0.36	26
6.1.92	152	32	4.43	0.75	0.89	0.13	0.54	26
13.1.92	190	45	3.85	0.92	0.97	0.13	0.33	23
20.1.92	175	38	3.37	0.66	0.80	0.11	0.33	20
27.1.92	170	39	3.69	0.58	0.92	0.15	0.38	20
3.2.92	163	40	2.81	0.57	0.82	0.12	0.34	23
10.2.92	145	42	2.30	0.63	1.06	0.11	0.41	20
17.2.92	136	36	2.53	0.56	0.99	0.12	0.35	17

Targets:

Ca	125 - 200
Mg	25 - 40
Fe	2 - 3
Zn	0.2
Mn	0.5
Cu	0.1
B	0.3

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Table 26. **Analysis of Nutrient Concentration in Feed Solutions**

Sand

Planting II

Date	Nutrient Concentration (mg/l)							
	Ca	Mg	Fe	Zn	Mn	Cu	B	Na
4.11.91	174	30	1.28	0.07	0.13	0.06	0.27	40
11.11.91	184	40	2.23	0.12	0.36	0.08	0.35	30
18.11.91	163	35	2.44	0.13	0.40	0.09	0.28	23
25.11.91	198	56	3.90	0.19	0.59	0.16	0.42	24
2.12.91	177	53	3.71	0.28	0.62	0.18	0.44	22
9.12.91	153	47	2.66	0.18	0.46	0.16	0.33	20
16.12.91	174	54	3.31	0.26	0.68	0.15	0.39	21
30.12.91	139	40	2.74	0.22	0.49	0.15	0.45	20
6.1.92	136	42	3.03	0.31	0.58	0.16	0.50	29
13.1.92	162	48	2.82	0.34	0.60	0.16	0.32	20
20.1.92	147	43	2.58	0.19	0.59	0.12	0.33	19
27.1.92	121	48	0.86	0.18	0.54	0.12	0.48	18
3.2.92	151	87	0.61	0.19	1.19	0.13	0.68	25
10.2.92	116	79	0.34	0.14	0.88	0.04	0.46	19
17.2.92	94	32	0.30	0.10	0.67	0.03	0.31	20

Targets:

Ca	125 - 200
Mg	25 - 40
Fe	2 - 3
Zn	0.2
Mn	0.5
Cu	0.1
B	0.3

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Table 27. **Analysis of Nutrient Concentration in Feed Solutions**

Probase

Planting II

	Nutrient Concentration (mg/l)							
Date	**Ca**	**Mg**	**Fe**	**Zn**	**Mn**	**Cu**	**B**	**Na**
4.11.91	156	46	0.56	0.06	<0.10	0.04	0.46	31
11.11.91	218	45	2.50	0.09	<0.10	0.15	0.43	21
18.11.91	208	35	2.66	0.10	0.20	0.13	0.29	18
25.11.91	224	46	4.31	0.15	0.21	0.13	0.38	22
2.12.91	214	40	3.33	0.18	0.26	0.14	0.27	19
9.12.91	225	41	3.69	0.13	0.34	0.10	0.30	19
16.12.91	242	38	3.38	0.07	0.33	0.11	0.22	20
30.12.91	184	21	1.30	0.06	0.16	0.07	0.21	18
6.1.92	192	17	0.79	0.07	0.11	0.07	0.18	16
13.1.92	237	21	1.22	0.10	0.14	0.07	0.10	19
20.1.92	213	17	0.99	0.15	<0.1	0.06	0.13	19
27.1.92	217	13	1.68	0.11	<0.1	0.09	0.08	18
3.2.92	135	14	0.61	0.10	0.10	0.03	0.16	18
10.2.92	113	19	0.21	0.13	0.34	0.02	0.20	15
17.2.92	98	10	0.65	0.13	<0.1	0.02	0.03	17

Targets:

Ca	125 - 200
Mg	25 - 40
Fe	2 - 3
Zn	0.2
Mn	0.5
Cu	0.1
B	0.3

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Table 28.

Leaf Analyses

Aeroponics

Planting II

Variety		% Dry Matter		% N		% P		% K		% Mg		% Mn	
		Peat	Jute	Peat	Jute	Peat	Jute	Peat	Jute	Peat	Jute	Peat	Jute
Delta	a	9.9	12.7	4.27	3.70	0.78	0.39	5.30	6.30	0.41	0.32	110	67
	b	12.4	11.2	3.63	4.08	0.58	0.61	5.60	7.01	0.34	0.35	93	92
	c	10.7	11.1	?	3.57	0.78	0.54	6.56	6.26	0.50	0.33	148	107
	d	12.1	11.7	3.70	4.16	0.51	0.56	5.04	6.09	0.30	0.30	76	72
	e	9.1	8.5	4.40	4.43	0.48	0.66	7.75	8.92	0.46	0.39	235	225
Snowdon	a	10.4	10.2	4.19	4.52	0.51	0.58	6.00	5.93	0.40	0.31	82	108
	b	12.4	10.8	3.48	4.08	0.46	0.48	4.68	5.68	0.31	0.32	84	108
	c	10.8	9.6	3.75	4.27	0.53	0.58	5.90	6.34	0.37	0.33	89	107
	d	11.9	12.1	3.92	4.45	0.50	0.49	5.36	5.65	0.30	0.30	78	107
	e	8.8	8.0	4.89	4.92	0.51	0.64	5.98	6.85	0.50	0.45	270	280

Key:

a - 2 days before start of short days
b - 1 week after start of short days
c - start of interruption
d - end of interruption
e - at maturity

APPENDIX IV

Table 29. **Leaf Analyses**

Sand

Planting II

Variety		% Dry Matter	% N	% P	% K	% Mg	% Mn
Delta	a	8.3	4.32	0.69	5.49	0.32	145
	b	9.0	3.95	0.62	6.63	0.31	133
	c	8.5	4.02	0.63	6.78	0.32	146
	d	8.6	4.39	0.50	6.08	0.34	90
	e	7.1	4.77	0.70	9.14	0.34	290
Snowdon	a	8.4	4.37	0.53	6.46	0.33	128
	b	9.8	4.40	0.52	5.45	0.30	91
	c	8.5	4.25	0.53	6.33	0.36	137
	d	9.8	4.33	0.40	5.27	0.29	61
	e	8.7	5.16	0.64	6.23	0.50	174

Key:

a - Two days before start of short days
b - One week after start of short days
c - Start of interruption
d - End of interruption
e - At maturity

APPENDIX IV

Table 30.

Leaf Analyses
Probase
Planting II

Variety		% Dry Matter	% N	% P	% K	% Mg	% Mn
Delta	a	8.5	4.25	0.69	6.56	0.40	96
	b	9.3	4.12	0.56	6.46	0.40	100
	c	8.3	3.89	0.62	6.28	0.38	111
	d	8.1	4.29	0.64	6.45	0.27	120
	e	7.0	4.49	0.48	8.79	0.40	180
Snowdon	a	8.2	4.63	0.52	4.20	0.26	88
	b	9.0	4.29	0.48	5.59	0.33	63
	c	7.1	4.24	0.53	6.16	0.36	74
	d	10.3	4.14	0.49	4.95	0.28	91
	e	8.2	4.64	0.51	6.43	0.51	153

Key:

a - Two days before start of short days
b - One week after start of short days
c - Start of interruption
d - End of interruption
e - at maturity

APPENDIX IV

Table 31.

Leaf Analyses
Soil
Planting II

Variety		% Dry Matter	% N	% P	% K	% Mg	% Mn
Delta	a	11.0	4.15	0.67	6.38	0.21	212
	b	8.1	3.83	0.68	6.32	0.29	255
	c	8.0	-	0.63	6.16	0.30	218
	d	8.7	4.01	0.55	5.62	0.23	179
	e	7.7	4.32	0.47	7.99	0.34	285
Snowdon	a	9.1	4.68	0.55	5.90	0.36	222
	b	9.3	4.16	0.52	5.69	0.31	215
	c	8.4	4.00	0.58	6.05	0.35	260
	d	10.4	3.55	0.42	4.69	0.27	169
	e	8.8	4.75	0.39	4.94	0.34	275

Key:
a - Two days before start of short days
b - One week after start of short days
c - Start of interruption
d - End of interruption
e - at maturity

APPENDIX V

Table 1. Systems comparison of plant height (cm) of *Delta* at key stages throughout the life of the crop. Planting III.

Assessment Stage	Plant height (cm) relative to system (including aeroponic irrigation frequency and propagation media)						
	Aeroponic				Hydroponic - Probase	Hydroponic - Sand	Soil
	Dutch [a]	English	Dutch	English			
	(Jute)		(Peat)		(Peat)	(Peat)	(Peat)
1.	9.1 [b]	11.4	15.9	18.4	19.3	19.7	17.3
2.	15.2	15.8	25.8	25.5	35.1	35.5	31.7
3.	30.1	29.6	39.9	40.1	52.8	52.9	51.4
4.	48.0	56.0	56.7	65.0	80.9	81.1	78.4

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Irrigation frequency regime, Dutch vs. English.

[b] = Mean of 20 replicate plants per treatment.

APPENDIX V

Table 2. Systems comparison of plant height (cm) of *White Fresco* at key stages throughout the life of the crop. Planting III.

Assessment stage	Plant height (cm) relative to system: Hydroponic - Probase (Peat)	Hydroponic - Sand (Peat)	Soil (Peat)
1.	19.3 [a]	18.8	14.7
2.	32.8	33.8	31.8
3.	55.3	54.5	53.3
4.	81.3	82.2	81.5

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Mean of 20 replicate plants per treatment.

APPENDIX V

Table 3. Systems comparison of stem fresh weight (g) of *Delta* at key stages throughout the life of the crop. Planting III.

Assessment Stage	Stem fresh weight (g) relative to system (including aeroponic irrigation frequency and propagation media)						
	Aeroponic				Hydroponic - Probase	Hydroponic - Sand	Soil
	Dutch [a]	English	Dutch	English			
	(Jute)		(Peat)		(Peat)	(Peat)	(Peat)
1.	2.5 [b]	3.2	7.5	8.8	12.2	11.7	9.9
2.	11.7	10.2	16.4	13.3	32.6	34.6	26.6
3.	37.1	28.5	36.4	30.3	52.3	62.0	48.2
4.	69.2	93.2	83.7	90.7	108.0	113.5	99.3

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Irrigation frequency regime, Dutch vs. English.

[b] = Mean of 15 replicate plants per treatment.

APPENDIX V

Table 4. Systems comparison of stem fresh weight (g) of *White Fresco* at key stages throughout the life of the crop. Planting III.

Assessment Stage	Stem fresh weight (g) relative to system		
	Hydroponic - Probase (Peat)	Hydroponic - Sand (Peat)	Soil (Peat)
1.	12.8 [a]	19.0	12.0
2.	46.7	45.7	38.9
3.	73.9	75.6	62.6
4.	130.3	144.1	97.0

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Mean of 15 replicate plants per treatment.

APPENDIX V

Table 5. Systems comparison of stem dry weight (g) of *Delta* at key stages throughout the life of the crop. Planting III.

Assessment Stage	Stem dry weight (g) relative to system (including aeroponic irrigation frequency and propagation media)						
	Aeroponic				Hydroponic - Probase	Hydroponic - Sand	Soil
	Dutch [a]	English	Dutch	English			
	(Jute)		(Peat)		(Peat)	(Peat)	(Peat)
1.	0.5 [b]	0.4	0.7	1.1	0.9	1.0	1.0
2.	1.4	1.5	2.7	2.5	3.4	3.4	2.9
3.	3.8	3.1	5.0	4.1	6.0	6.3	5.0
4.	10.4	13.2	14.1	15.0	15.5	16.8	15.7

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Irrigation frequency regime, Dutch vs. English.

[b] = Mean of 15 replicate plants per treatment.

APPENDIX V

Table 6. Systems comparison of stem dry weight (g) of *White Fresco* at key stages throughout the life of the crop. Planting III.

	Stem dry weight (g) relative to system		
Assessment Stage	Hydroponic - Probase (Peat)	Hydroponic - Sand (Peat)	Soil (Peat)
1.	1.5 [a]	1.7	1.2
2.	4.2	4.4	4.0
3.	7.7	7.9	6.1
4.	18.4	21.2	13.8

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Mean of 15 replicate plants per treatment.

APPENDIX V

Table 7. Systems comparison of leaf area (cm^2) of *Delta* at key stages throughout the life of the crop. Planting III.

Assessment Stage	Leaf area (cm^2) relative to system (including aeroponic irrigation frequency and propagation media)						
	Aeroponic				Hydroponic - Probase	Hydroponic - Sand	Soil
	Dutch [a]	English	Dutch	English			
	(Jute)		(Peat)		(Peat)	(Peat)	(Peat)
1.	81 [b]	82	164	136	228	205	216
2.	108	123	268	375	552	591	514
3.	483	798	427	575	957	920	954
4.	418	669	426	585	737	823	772

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Irrigation frequency regime, Dutch vs. English.

[b] = Mean of 5 replicate plants per treatment.

APPENDIX V

Table 8. Systems comparison of leaf area (cm^2) per unit stem length (cm) of *Delta* at key stages throughout the life of the crop. Planting III.

	Unit leaf area (cm^2/cm) relative to system (including aeroponic irrigation frequency and propagation media)						
	Aeroponic				Hydroponic - Probase	Hydroponic - Sand	Soil
	Dutch [a]	English	Dutch	English			
Assessment Stage	(Jute)		(Peat)		(Peat)	(Peat)	(Peat)
1.	8 [b]	9	6	8	11	10	11
2.	8	11	8	13	18	16	17
3.	14	17	25	15	18	18	19
4.	9	11	12	9	9	11	5

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Irrigation frequency regime, Dutch vs. English.

[b] = Mean of 5 replicate plants per treatment.

APPENDIX V

Table 9. Systems comparison of leaf area (cm^2) of *White Fresco* at key stages throughout the life of the crop. Planting III.

Assessment Stage	Leaf area (cm^2) relative to system		
	Hydroponic - Probase (Peat)	Hydroponic - Sand (Peat)	Soil (Peat)
1.	356 [a]	337	278
2.	822	774	605
3.	1172	1009	1187
4.	1237	895	932

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Mean of 5 replicate plants per treatment.

APPENDIX V

**Table 10. Systems comparison of leaf area (cm^2) per unit stem length (cm) of *White Fresco* at key stages throughout the life of the crop.
Planting III.**

Assessment Stage	Unit leaf area (cm^2/cm) relative to system		
	Hydroponic - Probase (Peat)	Hydroponic - Sand (Peat)	Soil (Peat)
1.	18	18	16
2.	25	22	20
3.	22	18	23
4.	15	11	12

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Mean of 5 replicate plants per treatment.

APPENDIX V

Table 11. Root discoloration of *Delta* at key stages throughout the life of the crop. Planting III.

Assessment Stage	Percentage root area discoloured relative to system						
	Aeroponic				Hydroponic - Probase	Hydroponic - Sand	Soil
	Dutch [a]	English	Dutch	English			
	(Jute)		(Peat)		(Peat)	(Peat)	(Peat)
1.	8.4 [b]	10.1	4.4	0.8	3.6	22.0	2.0
2.	-	57.5	93.5	57.5	23.5	-	75.5
3.	47.5	65.5	37.0	39.0	2.5	3.5	70.5
4.	60.0	64.5	50.0	49.0	0.5	0.0	-

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Irrigation frequency regime, Dutch vs. English.

[b] = Mean percentage root area discoloration from 5 plant root systems.

APPENDIX V

Table 12. Root disease assessments of *Delta* at key stages throughout the life of the crop. Planting III.

Percentage of plants showing fungal growth (a) identified as *Pythium* spp. (b) identified as *Thielaviopsis* (relative to system and propagation media)

Assessment Stage	Aeroponic Dutch [a] (Jute)	Aeroponic English (Jute)	Aeroponic Dutch (Peat)	Aeroponic English (Peat)	Hydroponic - Probase (Peat)	Hydroponic - Sand (Peat)	Soil (Peat)
(a) *Pythium* spp.							
1.	100 [b]	50	67	50	67	83	33
2.	-	100	100	80	50	-	100
3.	100	100	100	100	30	20	100
4.	100	100	100	100	10	0	-
(b) *Thielaviopsis* spp.							
1.	67 [c]	0	17	0	17	17	17
2.	-	100	40	50	0	-	60
3.	20	10	0	0	0	0	60
4.	40	40	30	20	0	0	-

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Irrigation frequency regime, Dutch vs. English.

[b] and [c] = Percentage recovery from 5 replicate plants sampled per treatment.

APPENDIX V

Table 13. Root discoloration of *White Fresco* at key stages throughout the life of the crop. Planting III.

Assessment Stage	Percentage root area discoloured relative to system		
	Hydroponic - Probase (Peat)	Hydroponic - Sand (Peat)	Soil (Peat)
1.	12.5 [a]	1.6	0.8
2.	64.5	61.0	89.5
3.	2.3	3.9	10.5
4.	1.1	0.7	0.5

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a] = Mean percentage root area discoloration from 5 plant root systems.

APPENDIX V

Table 14. Root disease assessments of *White Fresco* at key stages throughout the life of the crop. Planting III.

Percentage of plants showing fungal growth (a) identified as *Pythium* spp. (b) identified as *Thielaviopsis* spp. (relative to system and propagation media)

Assessment Stage	Hydroponic - Probase (Peat)	Hydroponic - Sand (Peat)	Soil (Peat)
(a) *Pythium* spp.			
1.	100 [a]	33	17
2.	100	10	100
3.	20	70	90
4.	10	10	10
(b) *Thielaviopsis* spp.			
1.	83 [b]	0	0
2.	20	70	100
3.	0	0	0
4.	0	0	0

Assessment stage:

1.	Two days before start of short days	03.04.92
2.	At start of interruption	18.04.92
3.	One week after end of interruption	30.04.92
4.	At harvest	08.06.92

[a and b] = Percentage recovery from 5 replicate plants sampled per treatment.

APPENDIX V

Table 15. Systems comparison of grade out at harvest and total crop duration *Delta* and *White Fresco*. Planting III.

Grade out (wraps per 1000 stems planted[a]) and total crop duration (days) relative to system

Assessment Stage	Aeroponic Dutch (Jute)	Aeroponic English (Jute)	Aeroponic Dutch (Peat)	Aeroponic English (Peat)	Hydroponic - Probase (Peat)	Hydroponic - Sand (Peat)	Soil (Peat)
Delta							
Wraps per 1000 stems	47.2	50.6	46.1	49.0	57.3	58.5	44.8
Crop duration	80.2	80.2	81.2	80.5	80.3	80.6	75.4
Fresco							
Wraps per 1000 stems	-	-	-	-	49.8	49.9	49.9
Crop duration	-	-	-	-	83.7	83.0	84.5

[a] = Note that this Grade-out is not directly comparable with current commercial specification. It refers to the sum of total stems in each grade category (10, 13, 16, 19, 22, 25), each total divided by its respective grade (10, 13, etc), and the sum then divided by total number of stems cut (including waste).

APPENDIX V

Table 16. Effect of production system on shelf-life of *Delta* and *White Fresco*. Planting III.

Shelf-life Stage	Number of days taken to deteriorate from shelf-life stage 1 to stage 2 and stage 2 to stage 3 relative to system (and propagation media)						
	Aeroponic				Hydroponic - Probase	Hydroponic - Sand	Soil
	Dutch	English	Dutch	English			
	(Jute)		(Peat)		(Peat)	(Peat)	(Peat)
Delta							
1 → 2	5.4 [a]	5.8	5.4	6.4	7.0	7.0	5.2
2 → 3	13.6 [a]	13.2	14.6	11.6	13.0	11.2	14.8
Total	19.0 [b]	19.0	20.0	18.0	20.0	18.2	20.0
White Fresco							
1 → 2	-	-	-	-	8.2 [a]	6.0	10.0
2 → 3	-	-	-	-	6.0 [a]	9.4	4.0
Total					14.2 [b]	15.4	14.0

[a] = Mean number of days taken to deteriorate, 5 stems per treatment

Stage 1 = fully expanded flowers

Stage 2 = partial deterioration

Stage 3 = complete deterioration

[b] = Total time taken to deteriorate completely.

APPENDIX V

Table 17. Systems comparison of water usage throughout the life of the crop. Planting III.

Week Number	Mean volume of water applied[a] daily (litres) Aeroponic	Hydroponic - Probase	Hydroponic - Sand	Soil
14	10.5	83.3	31.8	48.3
15	8.8	82.5	38.7	73.1
16	9.6	94.1	40.7	56.7
17	12.6	97.6	44.6	81.7
18	13.0	89.9	48.2	83.6
19	13.7	89.9	57.5	95.3
20	13.6	85.7	59.2	108.6
21	15.4	82.8	62.7	137.3
22	15.7	71.2	59.0	118.6
23	15.5	64.6	54.8	104.4

[a] Applied = top up volume added to 'closed' aeroponic and hydroponic tands of recirculated solution and actual volume applied to 'open' soil bed.

[b] Bed area per system approximately = 25 m^2

APPENDIX V

Table 18. **Analysis of Feed Solutions**
Aeroponics
Planting III

			Nutrient Concentration (mg/l)			
Date	**pH**	**μS at 20°C**	**NO_3**	**NH_4**	**P**	**K**
23.3.92	6.5	2200	146	11.0	53	374
30.3.92	6.0	1870	165	7.0	34	249
6.4.92	5.8	2070	152	6.0	34	268
13.4.92	7.6	2030	189	6.6	25	336
20.4.92	6.5	2210	206	1.8	38	383
27.4.92	6.4	2170	175	<1.0	47	357
4.5.92	6.3	2300	186	2.0	46	375
11.5.92	6.3	2190	179	1.2	42	364
18.5.92	6.3	1970	175	<1.0	40	336
25.5.92	5.9	2160	200	<1.0	37	290
1.6.92	6.4	2130	169	<1.0	35	287
8.6.92	5.7	2160	184	1.4	46	333

Targets:

pH	5.5 - 5.8
μS	1600 μS at 20°C, 1750 μS at 25°C
NO_3	125 - 175
NH_4	<1
P	25 - 35
K	200 - 300

APPENDIX V

Table 19. **Analysis of Feed Solutions**

Sand

Planting III

Date	pH	μS at 20°C	Nutrient Concentration (mg/l) NO_3	NH_4	P	K
23.3.92	6.8	1870	157	5.0	40	274
30.3.92	6.6	1680	138	3.0	40	231
6.4.92	6.4	1720	124	1.0	39	249
13.4.92	6.6	1560	115	1.4	48	266
20.4.92	6.6	1910	132	1.9	54	345
27.4.92	6.6	2090	152	2.9	55	361
4.5.92	6.6	2050	175	2.6	41	310
11.5.92	6.3	1970	159	2.8	45	323
18.5.92	6.5	1940	176	2.8	34	327
25.5.92	6.7	2120	192	1.9	41	322
1.6.92	3.1	2370	198	<1.0	26	297
8.6.92	5.2	2220	195	2.5	48	346

Targets:

pH 5.5 - 5.8

μS 1600 μS at 20°C, 1750 μS at 25°C

NO_3 125 - 175

NH_4 <1

P 25 - 35

K 200 - 300

APPENDIX V

Table 20. **Analysis of Feed Solutions**

Probase

Planting III

			Nutrient Concentration (mg/l)			
Date	**pH**	**μS at 20°C**	**NO_3**	**NH_4**	**P**	**K**
23.3.92	7.8	700	49	<1.0	4	36
30.3.92	7.4	1490	123	2.0	17	199
6.4.92	6.7	1730	116	1.0	32	271
13.4.92	7.3	1870	118	1.6	56	406
20.4.92	6.6	1480	101	<1.0	33	228
27.4.92	6.2	1920	140	2.0	53	291
4.5.92	6.0	1940	166	<1.0	37	313
11.5.92	3.2	1070	75	<1.0	7	56
18.5.92	7.0	1200	82	1.1	11	125
25.5.92	7.1	850	78	<1.0	3	43
1.6.92	6.8	915	74	<1.0	3	52
8.6.92	6.8	1700	102	<1.0	45	275

Targets:

pH	5.5 - 5.8
μS	1600 μS at 20°C, 1750 μS at 25°C
NO_3	125 - 175
NH_4	<1
P	25 - 35
K	200 - 300

APPENDIX V

Table 21. **Analysis of Nutrient Concentration in Feed Solutions**
Aeroponics
Planting III

	Nutrient Concentration (mg/l)							
Date	**Ca**	**Mg**	**Fe**	**Zn**	**Mn**	**Cu**	**B**	**Na**
23.3.92	178	53	3.39	0.82	1.25	0.19	0.43	25
30.3.92	150	37	2.35	0.77	1.01	0.11	0.33	22
6.4.92	136	38	2.45	0.59	0.91	0.12	0.29	21
13.4.92	226	33	6.34	0.35	0.42	0.09	0.43	30
20.4.92	163	45	4.69	0.72	1.02	0.15	0.40	24
27.4.92	168	60	3.26	0.67	1.27	0.16	0.56	28
4.5.92	184	59	4.78	0.73	1.33	0.16	0.53	28
11.5.92	191	59	4.27	0.75	1.13	0.16	0.53	29
18.5.92	204	58	4.18	0.80	0.98	0.15	0.51	32
25.5.92	195	52	3.46	0.70	0.90	0.16	0.50	30
1.6.92	202	49	3.08	0.65	0.72	0.15	0.45	29
8.6.92	196	50	3.58	0.64	0.68	0.15	0.51	26

Targets:

Ca	125 - 200
Mg	25 - 40
Fe	2 - 3
Zn	0.2
Mn	0.5
Cu	0.1
B	0.3

APPENDIX V

Table 22. **Analysis of Nutrient Concentration in Feed Solutions**

Sand

Planting III

	Nutrient Concentration (mg/l)							
Date	**Ca**	**Mg**	**Fe**	**Zn**	**Mn**	**Cu**	**B**	**Na**
23.3.92	168	57	1.33	0.18	0.39	0.13	0.41	25
30.3.92	152	47	1.44	0.20	0.67	0.09	0.40	21
6.4.92	131	42	1.30	0.21	0.68	0.10	0.37	19
13.4.92	157	50	1.98	0.25	0.77	0.11	0.53	25
20.4.92	139	60	2.46	0.30	0.83	0.19	0.58	24
27.4.92	149	66	1.89	0.30	0.93	0.22	0.61	26
4.5.92	170	52	3.67	0.34	1.04	0.22	0.46	24
11.5.92	162	55	2.23	0.40	1.22	0.15	0.48	24
18.5.92	191	44	4.82	0.51	0.83	0.15	0.37	26
25.5.92	174	45	3.00	0.41	0.85	0.16	0.43	24
1.6.92	186	33	4.46	0.82	0.36	0.16	0.31	24
8.6.92	194	50	2.15	0.42	1.02	0.19	0.46	23

Targets:

Ca	125 - 200
Mg	25 - 40
Fe	2 - 3
Zn	0.2
Mn	0.5
Cu	0.1
B	0.3

APPENDIX V

Table 23. **Analysis of Nutrient Concentration in Feed Solutions**

Probase

Planting III

	Nutrient Concentration (mg/l)							
Date	**Ca**	**Mg**	**Fe**	**Zn**	**Mn**	**Cu**	**B**	**Na**
23.3.92	104	10	0.28	0.15	<0.10	0.03	0.09	17
30.3.92	140	28	2.54	0.19	0.12	0.07	0.24	21
6.4.92	118	42	1.65	0.18	0.24	0.11	0.36	20
13.4.92	139	70	2.18	0.22	0.42	0.16	0.66	27
20.4.92	93.7	41	0.69	0.13	0.28	0.06	0.32	18
27.4.92	139	70	0.81	0.19	0.91	0.20	0.58	22
4.5.92	174	58	2.84	0.28	1.01	0.20	0.46	24
11.5.92	92.3	16	0.47	0.13	0.15	0.03	0.13	16
18.5.92	134	18	1.68	0.22	0.20	0.06	0.19	20
25.5.92	119	10	0.62	0.17	<0.10	0.06	0.10	17
1.6.92	133	10	0.61	0.13	<0.10	0.05	0.12	19
8.6.92	114	51	0.33	0.13	0.36	0.09	0.52	18

Targets:

Ca	125 - 200
Mg	25 - 40
Fe	2 - 3
Zn	0.2
Mn	0.5
Cu	0.1
B	0.3

APPENDIX V

Table 24.

Leaf Analyses
Aeroponics
Planting III

Variety	Prop.	Irrigation		% Dry Matter	% N	% P	% K	% Mg	% Mn
Delta	Jute	English	a	17.2	3.78	0.43	4.41	0.30	136
			b	12.3	3.98	0.39	4.37	0.26	91
			c	9.5	6.33	0.75	8.64	0.27	138
		Dutch	a	13.0	3.37	0.36	3.85	0.27	148
			b	10.9	4.05	0.43	4.58	0.25	106
			c	9.3	5.81	0.60	7.56	0.29	119
	Peat	English	a	9.4	3.78	0.56	4.21	0.39	143
			b	11.5	5.64	0.52	6.03	0.33	110
			c	10.7	5.46	0.53	6.93	0.33	116
		Dutch	a	9.4	4.39	0.59	5.13	0.40	162
			b	11.1	4.63	0.53	5.76	0.37	131
			c	13.4	4.06	0.46	5.07	0.27	106

Key: a - Two days before start of short days
b - At start of interruption
c - One week after end of interruption

APPENDIX V

Table 25.

Leaf Analyses
Hydroponic
Planting III

Variety	System	Prop.		% Dry Matter	% N	% P	% K	% Mg	% Mn
Delta	Sand	Peat	a	6.6	5.28	0.87	7.04	0.42	164
			b	8.5	5.79	0.74	7.89	0.42	164
			c	9.1	5.93	0.63	7.63	0.42	124
White Fresco			a	7.2	5.03	0.75	7.28	0.44	149
			b	8.7	5.31	0.64	8.16	0.41	154
			c	9.8	5.20	0.66	7.72	0.37	134
Delta	Probase	Peat	a	7.7	5.12	0.76	7.04	0.43	177
			b	9.4	5.82	0.66	7.48	0.43	105
			c	8.7	5.95	0.51	7.72	0.36	109
White Fresco			a	7.2	5.27	0.63	7.52	0.44	149
			b	8.4	5.84	0.82	8.07	0.48	132
			c	8.9	5.42	0.77	7.95	0.42	138

Key: a - 2 days before start of short days
b - Start of interruption
c - One week after end of interruption

APPENDIX V

Table 26.

Leaf Analyses

Soil

Planting III

Variety	Prop.		% Dry Matter	% N	% P	% K	% Mg	% Mn
Delta	Peat	a	8.0	4.54	0.83	6.07	0.46	310
		b	8.7	5.62	0.54	6.79	0.49	180
		c	8.9	5.75	0.53	7.38	0.43	157
White Fresco		a	7.7	4.51	0.65	6.37	0.45	219
		b	9.1	5.57	0.63	6.94	0.47	230
		c	9.3	5.33	0.55	7.08	0.39	179

Key: a - 2 days before start of short days
b - Start of interruption
c - One week after end of interruption

Appendix VI

Plate 1 **Aeroponic - root moistening system**

Early establishment in aeroponic system of plants propagated in jute plugs and peat blocks

Maturing crop in aeroponic system

Appendix VI

Plate 2 Hydroponic system - sand

Early establishment in sand-based hydroponic system of plants conventionally propagated in peat blocks

Maturing crop in sand-based hydroponic system

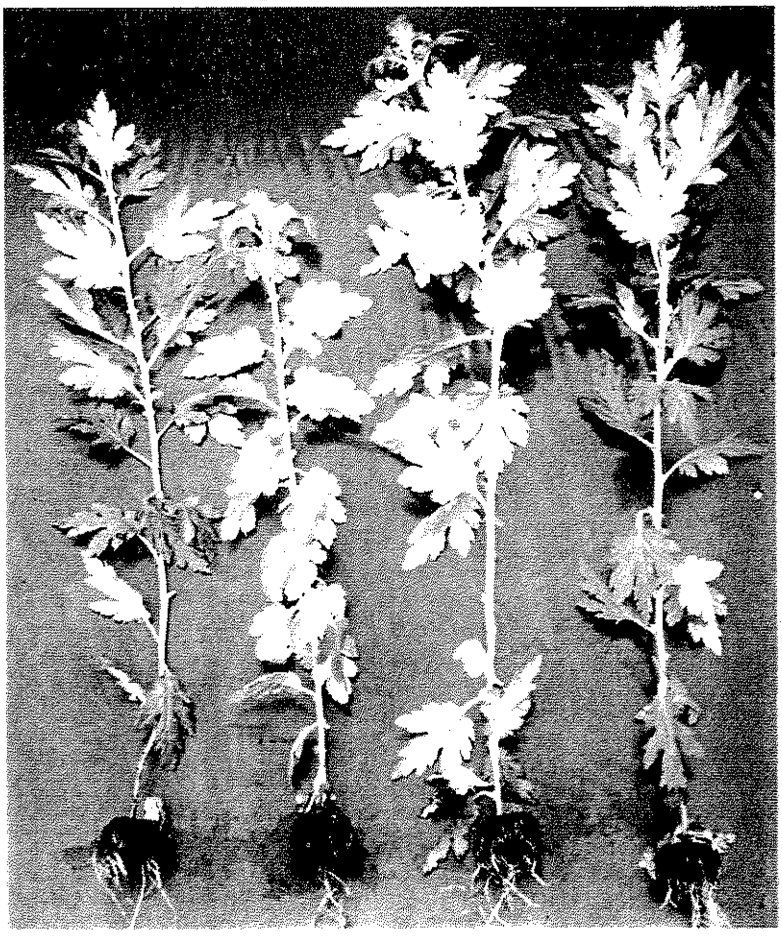
Appendix VI

Plate 3 Systems comparison of growth taken at end of interruption **Planting II**

Delta

Soil Aeroponic Sand Probase

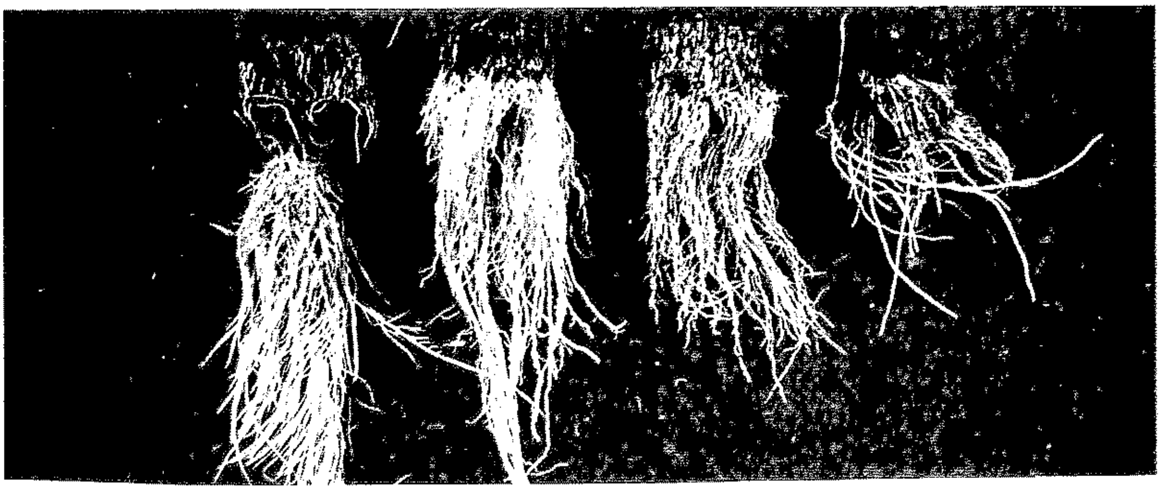
Snowdon



Appendix VI

Plate 4 Systems comparison of root growth one week after end of interruption Planting III

Delta



Aeroponic Sand Probase Soil

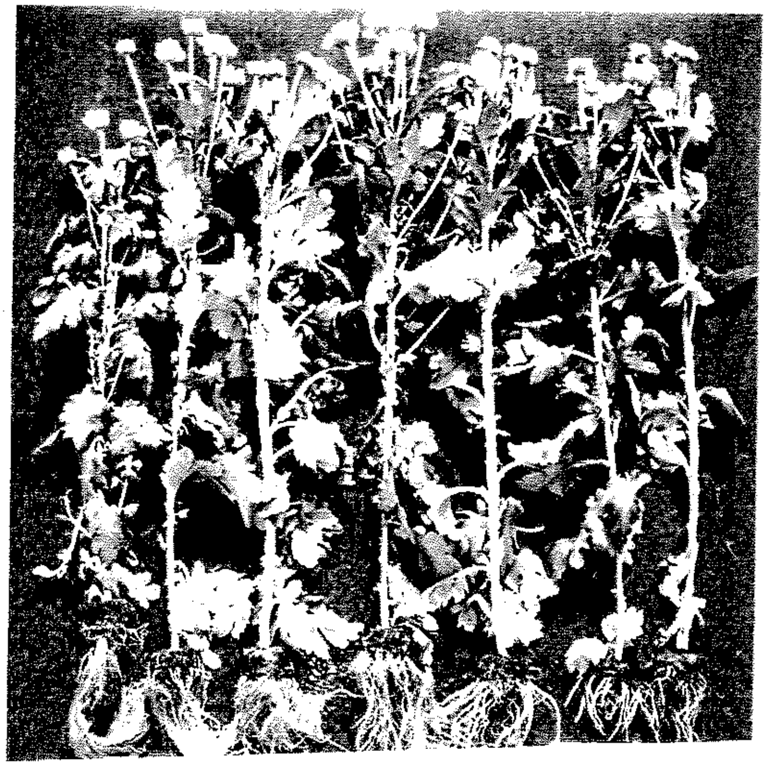
White Fresco

Sand Probase Soil

Appendix VI

Plate 5 Systems comparison of growth taken at harvest
Planting II

Delta



Aeroponic Sand Probase Soil

Sand

Appendix VI

Plate 6 Systems comparison of growth taken at harvest
Planting III

White Fresco

Probase Sand Soil

Sand Probase Soil

Appendix VII

Contract between HRI (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for a research/development project.

PROPOSAL

1. TITLE OF PROJECT: Contract No: PC/24

HYDROPONIC SYSTEMS FOR AYR CHRYSANTHEMUMS.

2. BACKGROUND AND COMMERCIAL DIRECTIVE:

The Dutch Government have specified that all glasshouse crops should be grown out of the soil in isolated systems to avoid pollution of the dykes. Many vegetable crops are already grown successfully in hydroponics as are crops such as roses, carnations and gerbera which are long term crops. The problems associated with short term crops such as chrysanthemums which need to be planted up to 4 times a year have yet to be satisfactorily solved.

In the UK the problem of pollution is less acute but there are other advantages of moving away from conventional bed systems. Pest and disease control might be aided particularly with pests pupating in the soil, and the need to steam sterilize beds could be eliminated. Cultivation of soil between crops would also be avoided.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY:

This is difficult to quantify until systems have been investigated.

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK:

To develop systems which can be used for short term bed crops in a closed nutritional environment. The long term aim would include work on pest and disease control, nutrition and labour saving techniques.

5. CLOSELY RELATED WORK - COMPLETED OR IN PROGRESS:

Commercial crops grown in rockwool have been partially successful in Holland and the experimental station at Naaldwijk have begun work on aeroponics. A visit to see Dutch work is planned shortly. A commercial concern in the UK using NFRT went bankrupt some years ago but was probably a little ahead of its time.

Efford EHS has looked at various techniques based on a conventional 1.5m bed over the last 10 years with varying degrees of success but the basis of nutrition and disease control is already established.

6. DESCRIPTION OF THE WORK:

An initial proposal must be sufficiently flexible to allow for development as work continues. It is anticipated that the project would begin with a comprehensive review of literature available to date with visits to appropriate establishments if possible. Initial work will begin in Spring 1991.

The initial treatments will include:

1. Conventional soil bed grown crop
2. An NFT system
3. A rockwool system
4. An aeroponic system.

Any system using rockwool leads to additional treatments after the first planting as the need to sterilize or replace comes into question.

Propagation techniques -

This is a key part of any system and propagation techniques would be included as subtreatments.

Previous trials with hydroponics have used either conventional peat raised plants or rockwool cubes of similar size. The cost of rockwool is prohibitive and the use of peat is undesirable in a hydroponic system particularly if solutions are being re-cycled.

Methods of propagation would be examined on all systems tried. These might include:

1. Bare root propagation
2. Peat blocks
3. Rockwool blocks
4. Rockwool plug trays

Progress of work -

It is anticipated that the first year will be occupied screening a range of possible systems and propagation techniques. The most promising systems will be examined in more detail in a second year which will be covered by a new contract.

Environmental factors -

Moves in Holland to encourage hydroponics are intended to develop completely closed systems with no waste solutions running into drainage systems. One of the main underlying principles of this work would be to keep to this principle as far as possible and to monitor carefully any unavoidable waste.

Varieties -

It has been suggested that a limited number of varieties should be used. Snowdon would be the main choice for winter work and possibly Fresco in the summer with Delta a possible variety for any season.

Trial layout -

Each main system examined will occupy one bed. Up to six beds each of 25 m can be made available for this trial. propagation systems will be examined within main growing beds as will varieties if a wider range than that mentioned above is required. Plot size will be kept as large as possible depending on the number of treatments required.

7. **COMMENCEMENT DATE AND DURATION:**

April 1 1991

To run initially on an ongoing basis for 18 months to Autumn 1992. The preliminary trial will begin in April '91; the first full trial will be planted in November '91 and the second full trial will be planted in March '92. The final report will be produced by the end of September 1992.

8. **STAFF RESPONSIBILITIES:**

Project Leader: R. Findlay
Other Staff: Dr F A Langton, Littlehampton

9. **LOCATION:**

Efford E H S

10. **COSTS:**

£24,000 over 18 months

11. PAYMENT

On each quarter day the Council will pay to the Contractor in accordance with the following schedule:

Quarter/Year	1991	1992
1	-	6000
2	- *	6000
3	- *	6000
4	6000	-

* The payments for the preliminary work have been included in the Contract payments for the main trials.

Contract No: PC/24

TERMS AND CONDITIONS

The Council's standard terms and conditions of contract shall apply.

Signed for the Contractor(s)

Signature....................................

Position.. Commercial & Marketing Manager HRI

Date.......... 21/9/92

Signed for the Contractor(s)

Signature....................................

Position....................................

Date....................................

Signed for the Council

Signature....................................

Position CHIEF EXECUTIVE

Date 2.9.92.