HORTICULTURE LINK PROJECT
HL0135LSF (Hort 215)

Overcoming the Loss of Methyl Bromide with a Competitive

and

Sustainable Soil-less

Strawberry Production System

Final Report

(October 1999 – March 2004)

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The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiments were carried out and the results obtained have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

APCI	*Atmospheric pressure chemical ionisation-gas phase analysis*
AFP	*Air Filled Porosity*
CU	*Chill Unit*
GH	*Glasshouse*
HI	*Harvest index*
IR	*Infra-red*
IRT	*Infra-red thermometry*
LAR	*Leaf area ratio (cm^2g^{-1})*
LVDT	*Linear variable displacement transducer*
LWR	*Leaf weight ratio*
MS	*Mass spectrometer*
SLA	*Specific leaf area (cm^2g^{-1})*
THB	*Thermal Heat Barrier*
WRAP	*Waste and Resources Action Programme*

GROWER SUMMARY

Project Summary

This project has investigated a range of parameters to help to develop a competitive and sustainable soil-less strawberry production system for the principal commercial varieties Elsanta and Everest. The optimum environmental conditions for growing Everest have been identified, which will help the industry to develop growing systems to create such conditions and improve total yields and quality. The work demonstrated that weigh cell technology is effective for monitoring irrigation requirements and improving control, although further work is required to refine this. Light interception must be maximised if optimum yields and fruit flavour/quality are to be achieved. Sugars have been shown to be important to flavour perception, which may assist in the development of a quantitative test for fruit quality. Bark based substrates have been identified as possible replacements for peat, but further refining of nutrition and irrigation delivery systems is required before these become commercially viable. In propagation, the use of field chilling and night break lighting can increase yields and the cropping period of Elsanta, but this technique is not yet commercially viable. The work has also demonstrated that the position of a plant on a runner in the propagation field has little influence on subsequent plant performance, confirming that the industry is already using the optimum propagation system.

Objectives of the Project

The overall aim of the project was to provide the scientific basis necessary for the development of a soil-less strawberry growing system for the UK, which is sustainable, environmentally responsible and cost effective. The system would be cropped continuously over an extended season (May – September) and yield over 50 t/ha of Class 1 fruit. This aim was tackled through a series of specific objectives:

1. **Define the responses of the strawberry plant to its water, light and thermal environments.**

(This will allow controlled flower production that will sustain long season cropping of Class 1 fruit with optimum flavour characteristics).

2. **Provide a quantitative description of resource partitioning between vegetative and reproductive growth.**

(Leading to the understanding needed to optimize fruit production and quality)

3. **Identify the best option from available growing media for fruit production over the extended season.**

(Enabling the move away from peat-based substrates)

4. **Determine the factors influencing plant quality during the pre-planting phase.**

(Plant material can then be pre-programmed to give optimum performance during extended cropping)

BACKGROUND AND EXPECTED DELIVERABLES

OBJECTIVE 1

Define the Responses of the Strawberry Plant to its Water, Light and Thermal Environments

Systems in which long-season production is achieved by means of a range of short-day and everbearer/day-neutral cultivars with overlapping seasons are reported to be more economical than those in which the cropping period of a single short-day cultivar is manipulated. The UK soft fruit industry has recently increased the production of everbearing strawberry varieties to exploit the lucrative out-of-season market. Significant improvement in breeding cultivars with greater fruit quality has made everbearer production for multiple retailers feasible, but the extended growing season makes the crop susceptible to high mid-summer temperatures. Heat induced cropping troughs, or thermo-dormancy, can reduce commercial everbearing strawberry yields by 30% (Grower, Week 34 2003). This topic is growing in importance within the context of climate change. Thermo-dormancy triggers in everbearing strawberry have been investigated in detail for the first time here.

For the development of an optimised long-season strawberry cropping system, a deeper understanding of the responses of the strawberry plant to its water, light and thermal environments was sought in eight experiments conducted within Objective 1. Work focused on the Junebearer 'Elsanta' and the everbearer 'Everest'.

Responses of the Strawberry Plant to its Water Environment

Controlled water stress applied during fruit development has been used in a number of crops to improve fruit flavour. The influence of such water stress seems to be due to root signalling causing diversion of assimilates to developing fruits. This would be expected to lead to increased fruit sugar levels but would also provide additional assimilates for the production of secondary flavour compounds, notably acids and fruit flavour volatiles. A number of problems are associated with using water stress for fruit flavour manipulation. For example, such techniques can only be used where plant water needs are provided by irrigation. There is also the physical problem of managing soil water potentials under rapidly changing environments, and finally any water stress may lead to an unacceptable yield loss.

A number of experiments on 'Elsanta' and 'Everest' were used to investigate the use of controlled water stress. These involved the development of an electronic system for the control of water stress, a preliminary investigation developing analytical techniques to measure the biochemical components of strawberry fruit flavour, and the use of these analytical techniques to investigate the influence of controlled water stress on fruit flavour.

Responses of the Strawberry Plant to its Light and Thermal Environment

Little was known about the temperature and light requirements for optimum fruit production in 'Everest'. In contrast to Junebearers, the prolonged season of everbearers causes vegetative growth and fruiting to coincide, so the influence of the environment on the balance of assimilate partitioning between vegetative and reproductive growth is of particular importance for optimised long-season production. Initial experiments concentrated on the response of 'Everest' to shade, and on systematically establishing the temperature optimum for fruiting; they also provided an analysis of the interaction between growth environment and resource distribution. Temperature

controlled glasshouse compartments were used to provide set-point temperatures of 10, 14, 18, 22, 26 and 30^{o}C.

Periods of high temperatures mid-season were found to result in heat induced cropping troughs (thermo-dormancy). The sensitivity to periods of high temperature exposure and the relevance of day/ night temperature integrals were examined in detailed transfer treatments from a commercial 'pipe and pot' system into controlled environment growth cabinets (Saxcils). This work confirmed the central role of high night temperatures in triggering thermo-dormancy.

The effect of photoperiod on flowering was also investigated, because of the need to understand the effect of seasonal change in light environment on flower initiation in everbearers. Previous research of the effects of photoperiod and temperature has tended to focus on Junebearing varieties because of their commercial dominance.

Shade tolerance is a consistent feature of strawberry species and cultivars. A main feature of shade tolerance found here for 'Everest' was the increase in leaf area per unit leaf weight. A specific experiment in year three examined the possibility of exploiting this increase in source capacity in 'Everest' by shading plants prior to fruit production.

OBJECTIVE 2

Provide a Quantitative Description of Resource Partitioning between Vegetative and Reproductive Growth

While the techniques for producing a high yielding strawberry crop in soiless systems are faily well established sometimes the flavour of the fruit is disappointing and can lead to rejection of a consignment by the retailer. The use of a soiless growing system gives growers the opportunity to more closely control the plant's growing environment compared to growing directly in the soil.

Experience in other crops grown in soiless systems, notably tomato, has shown that manipulation of the plants growing environment can be used to enhance flavour. The flavour work carried out

in LINK 215 was designed to investigate the components of strawberry flavour, to gain an understanding of some of the environmental factors that influence the production of flavour and to see if it could be enhanced by cultural means.

Two approaches were used to investigate flavour development. Based on the experience with tomatoes and some preliminary work with strawberry the application of a short period of water stress was used to try and enhance fruit flavour. In order to apply water stress an irrigation control system based on measuring the loss of water from growing bags was developed. The second approach to flavour investigation was based on the hypothesis that flavour compounds are synthesised from the products of phtosynthesis and therefore the amount of these compounds available to an individual fruit would depend upon the total amount of photosynthates (source) and their distribution between fruits (sinks). To investigate this aspect of flavour development the plant source was manipulated artificially by shading and the sink levels by fruit thinning.

In both aspects of the work fruit flavour was assessed by both chemical analysis and by taste panel.

The expected deliverables were the possibility of manipulating fruit flavour by water stress and the development of a system to monitor the applied water stress, a greater understanding of the source/sink relationships in flavour development which would lead to recommendations for crop management and some indication of the importantance of some specific flavour compounds in strawberry flavour perception.

OBJECTIVE 3

Identify the Best Option from Available Growing Media for Fruit Production over the Extended Season

The background to the work on substrates was the focus on a ‘sustainable’ system for growing strawberries outside of the soil. The substrate used for such systems has traditionally been peat, which is widely regarded as a non-renewable resource and, therefore, not ‘sustainable’. The substrate work was not a major part of the project but it was included because of the debate over

the environmental credentials of peat. A large proportion of UK strawberries are sold via the multiple retailers, who have policies for reduction in peat use in line with the DEFRA Biodiversity targets. Strawberry growers are, therefore, likely to come under pressure to reduce their reliance on peat for strawberry production in bags. The development of a completely novel, non-peat substrate for strawberry production was beyond the remit of this project. It was felt, however, that some research into the performance of existing alternatives, and their interactions with the other project research areas on the growing environment, water use and flavour, would be of value to the industry.

It is very difficult to define 'sustainability' when classifying substrates. Inorganic materials such as rockwool and perlite have technical advantages in soil-less systems as they are inert and plant nutrition can then be well controlled. However, they have high energy requirements for their production and are not biodegradable, so were not considered suitable test substrates. Organic renewable materials were therefore chosen – timber industry by-products, green compost and coir dust, a by-product from the coir fibre industry, but also now produced commercially for horticultural substrates.

Growing media based on these types of materials have been used in the ornamental horticulture sector but, apart from coir dust, there was little data on their use in strawberry production. Although coir dust has been successfully used for strawberry production in The Netherlands the Consortium for this project favoured a focus on more locally available materials.

The expected deliverables of the substrate work were the identification of renewable peat alternatives with potential for use in strawberry bags in the UK and information on the management of the crop, including water and nutritional requirements, when grown in these substrates.

OBJECTIVE 4

Determine the Factors Influencing Plant Quality During the Pre-Planting Phase

Factors that influence plant quality during the pre-planting phase, along with those that pre-conditioned the planting material are important determinants in producing maximum yields of Class 1 fruit. Any novel growing method will benefit considerably from a clear understanding of the most appropriate practical means to ensure pre-planting conditions are 'system-optimised'.

One of the most obvious factors influencing plant quality prior to planting is the impact of chilling temperatures during the dormant season. The effect of low temperatures ($\leq$10 ^{o}C), or 'chilling', on flowering in Junebearer cultivars is generally well established with inhibition, reducing or delaying further flower induction, if sufficient chilling is not given. In everbearer cultivars, the situation is less clear and some work suggests that they may have chilling requirements similar to Junebearers, while others report no chilling effects on everbearer flowering. For Junebearers, it is possible that cropping season length could be extended using the plants responses to a combination environment change, in particularly chilling and day-length.

Propagation of everbearing cultivars frequently involves the use of systems whereby "mother" plants are grown in containers with a peat-based substrate under glass, the containers being elevated off the ground. Stolons (runners) produced are harvested when the tip of the stolon reaches the ground. Such a system provides stolon plantlets of different ages and sizes, depending on their position relative to the mother plant. It is not however clear if this stolon runner plant variability has any carry-over effects on plant development and cropping potential.

To answer these questions two primary objectives were addressed; to determine the effects of chilling on everbearers and chilling and day-length on Junebearer plant performance, and to assess the effects of runner variability on plant growth and cropping potential. Work with a Junebearer concentrated on using different combinations of chilling and day-length to manipulate fruiting without compromising plant health, fruit quality or total yield.

These objectives were expected to deliver practical guidelines about the most appropriate way to use chilling in both everbearers and Junebearers to maximise cropping and crop quality over an extended season. Close examination of the natural variability of stolon runner plants was expected to deliver knowledge of how plant morphology influenced subsequent growth and development and whether this had any carry-over influence on cropping time, yield or fruit quality. All of these objectives included an evaluation of the current industry practice to ensure that an appropriate comparison could be made, if a change of practice was required.

PROJECT SUMMARY AND MAIN CONCLUSIONS

OBJECTIVE 1

Define the Responses of the Strawberry Plant to its Water, Light and Thermal Environments

Responses of the Strawberry Plant to its Water Environment

- Water stress is not suitable for fruit flavour manipulation in 'Elsanta' and 'Everest'.

- Irrigation could be controlled and optimised, in principle, by a computer-controlled weighing system, as tested in experiment1.

Responses of the Strawberry Plant to its Light Environment

- *Fragaria* is a shade tolerant genus. The experiments demonstrated that the strawberry plant does adapt to reduced light levels by increasing the leaf area. However, despite this increase in leaf area, the reduced light levels still resulted in a loss of yield.

- Reduced light levels led to a reduction in yield depending on temperature environment. In 'Everest' this was due to a reduction in crown numbers, identifying these as the limiting factor for yield potential.

- Reduced light levels lower fruit quality and flavour, by reducing the availability of assimilates for the production of flavour compounds in 'Elsanta' and 'Everest' (see also Objective 2). Fruit flavour analysis showed the importance of maximising light interception to minimise variation and optimise fruit flavour.

- Day-length did not significantly affect the initiation of floral meristems in 'Everest'.

Responses of the Strawberry Plant to its Thermal Environment

- A reduction in total seasonal flower initiation was found in 'Everest' exposed to temperatures of 26^{o}C and above. The number of microscopic flowers was, however, not as strongly affected as the rate of flower bud abortion.

- More but smaller berries were found at temperatures above 23^{o}C, indicating a capacity for yield compensation in 'Everest'.

- 'Everest' has a strikingly higher temperature optimum for yield (23^{o}C) than the Junebearer 'Elsanta' (15^{o}C).

- Periods of exposure to 26^{o}C (5-30 days) in July caused thermo-dormancy in 'Everest' in August. The severity of this depended on the length of exposure, but even a five-day exposure was capable of reducing yields by 14%.

- Short periods (5 days) of high temperature (26^{o}C) did, however, bring the July cropping peak forward by at least one week.

- A reduction in night-time temperature was shown to be beneficial for preventing or reducing thermo-dormancy during a potentially productive phase of growth in August.

OBJECTIVE 2

Provide a Quantitative Description of Resource Partitioning between Vegetative and Reproductive Growth

Responses of the Strawberry Plant to Source and Sink Strengths

- Light levels had a major effect on fruit flavour compounds with reduction in light integral reducing some fruit volatiles and sugar levels

- Harvest date had highly significant effects on flavour compounds

- Despite significant differences in sugar levels in sugars due to shading untrained taste panels were unable to detect differences in fruit flavour between shaded and non shaded plants

- Trained taste panels were able to detect differences

- Relatively short periods of low light intensity can have a significant influence on fruit flavour

Responses of the Strawberry Fruits to Their Light Environment

- Shading of individual fruits had no influence on the generation of fruit flavour compounds

- Taste panels could not detect any difference between shaded and non shaded fruit

OBJECTIVE 3

Identify the Best Option from Available Growing Media for Fruit Production over the Extended Season

- Initial analysis of media (Experiment 1) showed that alternatives to peat had acceptable physical and chemical characteristics.

- The pH in peat alternatives was generally higher, but these also have a greater chemical buffering capacity, so nutrient availability is adequate.

- There was evidence (Experiments 3 and 5) that substrates based on composted bark immobilised nitrogen, presumably as decomposition continues during the cropping period. However, the importance of this is questionable, since nutrients are continually supplied in fresh solution under commercial production conditions.

- Additional nitrogen in non-peat media (Experiments 5, 6 and 7) gave no yield advantage, confirming that the commercial practice of continually supplying nutrients in the irrigation water prevents any disadvantage from nitrogen immobilisation by the substrate. This suggests that the under-performance of non-peat media is not related to sub-optimal nitrogen supply through nitrogen immobilisation.

- Generally, effects of growing media were greater on fruit size than fruit number. For example, in Experiment 6, fruit in the peat treatment were larger, resulting in more fruit in Class 1 grade.

- In Experiment 7, with a bark/loam substrate, lower run-off treatments resulted in higher electrical conductivity than in higher run-off treatments, but there was no indication of phytotoxicity. However, lower run-off increased the risk of drought stress, so more careful control of irrigation and lower spatial variability in both water supply and water demand would be desirable.

OBJECTIVE 4

Determine the Factors Influencing Plant Quality During the Pre-Planting Phase

Effects of Chilling on Junebearer Plant Performance

- A combination of field chilling of 800 CU and night-break lighting of 35 days enabled secondary flower initiation to increase yield and cropping period of Elsanta.

- Night-break lighting increased yields initial cropping although it did not alter time to first crop.

- Less chilling produced a more uniform cropping profile, whilst greater chilling (especially that given in cold storage) resulted in a greater yield initially with less produced subsequently.

- The provision of field chilling had considerable benefits compared to cold storage, produced more berries overall (the result of greater flower initiation).

- Significantly fewer runners were produced with field chilling and lighter, smaller leaves resulted, increasing the yield potential; this was probably a result of antagonism between fruiting and vegetative growth.

Effects of Chilling on Everbearer Plant Performance

- Increasing chilling (applied to the variety Everest via cold storage for 2-10 weeks at +2 ^{0}C) decreased overall yields (end May - end August). Comparative yields for un-chilled plants and those subjected to 10 weeks chilling, were 864 and 483 g/plant respectively.

- Increased chilling resulted in a significant reduction in cropping ca. 100 days after completion of chilling treatments, but increased again subsequently. For example, un-chilled plants produced 321 g and 220 g/plant, compared to 36 g and 302 g/plant for plants subjected to 10 weeks chilling, in the July and August periods respectively.

- The everbearer 'Everest' given a 'polytunnel chilling treatment' produced the largest plants in the spring and these plants remained the largest throughout the cropping trial (to September) and had the highest fruit yields.

- The everbearer 'Everest' given a 'glasshouse chilling treatment' (minimum 5 ^{0}C) produced the smallest plants in the cropping trial (to September) and had the lowest fruit yields.

- Chilling 'Everest' at different temperatures and for different lengths of time produced plants, which in March varied significantly in size. The more chilling 'Everest' plants received the greater the reduction in size at spring planting.

- During the cropping season, initial differences in the size of 'Everest' plants were lost, with the exception of the longer chill plants (6 to 10 weeks) at –2 ^{0}C.

- Plants from the longest chilling treatments produced less fruit over the season compared to the milder chilling treatments and the un-chilled controls.

- Differences in crop quality (size class distribution) were small for 'Everest' plants chilled at different temperatures and different lengths of time.

Assess Effects of Runner Variability on Plant Performance

- Position and hence age of ramet (runner plant) on the original stolon, influences initial 'quality' of ramets used for propagation.

- Primary (oldest) ramets, closest to the mother plant, are larger overall originally, but have a lower proportion of roots compared to younger (tertiary) ramets.

- After preparation for propagation, initial size differences were no longer apparent with all ramets of similar total size, but position along the stolon exacerbates "rootiness" of younger ramets.

- Initially there was a significant trend for increased concentrations of N, P and K, and reduced concentrations of Ca, in younger ramets.

- Younger ramets established more successfully and quickly compared to older (primary) ramets.

- During subsequent growth, initial differences in mineral content disappeared, and differences in growth rate became less apparent.

- At end of propagation period, primary ramets were smaller overall compared to younger ramets.

- Differences in plant quality (size) along a propagation runner can be minimised by removing from mother plant in August.

- Despite differences in root mass of plants along a propagation runner, rooted plants were of a similar size and grew and cropped equally well.

- Plant position on an everbearer propagation runner does not have to influence the quality of the established plant or its cropping, providing the runner is of good quality.

FINANCIAL BENEFITS

OBJECTIVE 1

Define the Responses of the Strawberry Plant to its Water, Light and Thermal Environments

This work focussed on soil-less production systems, which also (predominantly) are protected cropping systems. Covers include semi-permanent structures using polythenes (e.g., Spanish tunnels) or more permanent structures under polythene or glass. In either case, average seasonal temperatures are increased. Thermo-dormancy has been found to reduce commercial everbearing strawberry yields by 30% (Grower, Week 34 2003). A deeper understanding of this physiological process gained in this study will enable mid to long-term financial benefits, by specifically targeting the reduction of night-time temperatures with new cladding materials and adaptations to crop husbandry methods. In the immediate future, the financial investment into heat-reducing polythenes compared to standard films, as well as increased venting may reduce the severity of the cropping trough, and therefore be financially worth while. For instance, the increased investment of £225 per hectare for cladding one hectare of Spanish tunnels with heat reducing polythene (e.g., Luminance THB) rather than standard film, would be regained with an increased production of up to 2 t/ha. This assumes that the heat reducing polythene was successful in reducing temperatures to a level that prevented thermodormancy from occurring.

OBJECTIVE 2

Provide a Quantitative Description of Resource Partitioning between Vegetative and Reproductive Growth

The work with water stress was rather disappointing since brief periods of controlled stress had little if any influence on the fruit flavour compounds and consequently had no effect on consumer taste perception. In addition even very short periods of water stress caused considerable reduction in crop yield. However the development of a water monitoring system could be useful in the longer term. It would allow irrigation needs to be met more closely than at present avoiding excessive run off which is both costly and environmentally unacceptable.

The work on flavour development showed that fruit sugars were important not only for the development of fruit sweetness but also for the perception of 'strawberry' flavour. The work was carried out on early and late protected crops and suggested that even a short period of low light intensity during fruit development, which could occur at these times, could have an adverse effect on flavour. The use of techniques to improve the plant's incident light environment such as reflective ground cover, clean glass and possibly a slight reduction in plant density (to reduce self shading) could reduce this adverse effect. The important role of sugar in flavour perception could also lead to better techniques in fruit flavour measurement since refractometry (which is currently used) has a number of problems. It is only really accurate with pure sucrose solutions and insoluble solids are known to interfere with the determination of the refractive index.

There may be financial benefits to be gained by reducing plant density, using reflective ground covers or employing other techniques to increase light interception with the intention of improving fruit flavour. However, where plant density is reduced and commercial yields decline, growers would need to receive a premium from customers for high quality fruit to make it financially viable.

OBJECTIVE 3

Identify the Best Option from Available Growing Media for Fruit Production over the Extended Season

There are unlikely to be short-term financial benefits from the use of non-peat substrates for strawberry production. However, in the long-term, peat will become less available and the price will therefore increase, which will make other materials more competitive. The multiple retailers regard peat use as a social responsibility issue along with pesticides, energy use and ethical trading and will require suppliers to demonstrate that they share their aspirations to reduce peat use. It is likely, therefore, that growers who supply multiple retailers in the UK will have to reduce peat use by changing to either reduced peat or peat-free substrates. This project has demonstrated that other substrates have the potential to replace peat for strawberry production. Although there was some yield reduction in the bark-based substrate it was not major and it is likely that this could be overcome with further research to optimise crop management. The project results and other research data suggest that, in the short-term, a blend of a bark, or other timber industry co-product, and peat (for example 50% bark) could be used as 'reduced peat' substrate, which would satisfy most customer requirements without compromising yield.

OBJECTIVE 4

Determine the Factors Influencing Plant Quality During the Pre-Planting Phase

Work showing the requirements for everbearer chilling and understanding the variability in runner plant development prior to planting highlighted some interesting results. It was however determined that chilling requirements could currently be easily met using an unheated polytunnel during the winter, which is current industry practice. Equally, despite stolon planting variability being apparent, this did not translate into cropping differences. The standard industry practice was again found to be the most appropriate. Both these conclusions indicate that as no change of practice is recommended there will be no financial changes to induce further benefits. The cropping of the Junebearer 'Elsanta' was clearly increased with improved marketable quality

using field chilling and night-break lighting, but the technique requires further development before it is likely to be economically beneficial. This is an area currently under further R&D project development and exploitation (See Exploitation Plan).

ACTION POINTS FOR GROWERS

OBJECTIVE 1

Define the Responses of the Strawberry Plant to its Water, Light and Thermal Environments

- Optimise the light environment for improved assimilate partitioning and flavour. Further work is required to identify the most cost-effective ways of doing this (see Financial Benefits section under objective 2).

- Temperature control wherever possible, to the optimum of 23^{o}C, for instance by the use of heat reducing films.

- Exposure of 'Everest' to temperatures of 26^{o}C and above should be balanced with cool night temperatures to reduce the occurrence of thermo-dormancy. This could be obtained with heat-reducing polythenes, improved venting and air circulation - to allow stored heat and long-wave radiation to escape during the night.

OBJECTIVE 2

Provide a Quantitative Description of Resource Partitioning between Vegetative and Reproductive Growth

- Optimise the light environment for improved assimilate partitioning and flavour (see also Objective 1). This is especially important during fruit ripening for flavour development. Further work is required to identify the most cost-effective ways of doing this (see Financial Benefits section under objective 2).

- The levels of sugars are important to flavour perception in strawberry. The development of a simple sugar measurement system (not BRIX) would assist the industry in the development of a quantitative test for fruit quality.

OBJECTIVE 3

Identify the Best Option from Available Growing Media for Fruit Production over the Extended Season

- In Experiment 7, with a bark/loam substrate, lower run-off treatments resulted in higher electrical conductivity than in higher run-off treatments, but there was no indication of phytotoxicity. However, lower run-off increased the risk of drought stress, so more careful control of irrigation and lower spatial variability in both water supply and water demand would be desirable.

- There is a need to understand the factors that cause peat to perform better than other growing media. Nitrogen nutrition does not appear to be a key factor. Further work has already begun to investigate the control of water and nitrogen delivery and the effect on yield, quality, flavour etc (See Exploitation Plan).

OBJECTIVE 4

Determine the Factors Influencing Plant Quality During the Pre-Planting Phase

- Maximise yield and marketable quality in 'Elsanta' with 800 CU of field chilling and 35 days of incandescent, night-break lighting (15 min. every hour from 2100 - 0500).

- Cold storage chilling of 'Elsanta' inhibits secondary flower initiation, and hence limits the cropping duration.

- Cold storage chilling at temperatures above 3.9 ^{0}C cannot be recommended, as plant health suffers and plant performance deteriorates.

- The timing of runner harvesting is important, as runner quality in general declines in late autumn. To maximise quality runners should be harvested prior to any decline in condition of ramet one (oldest on the stolon).

- Despite apparent inherent differences, at harvest, in ramet size and subsequent growth and development all ramets from a stolon with 4 ramets yield very similar total crops. This shows that 'propagators' and 'growers' do not need to worry about apparent quality differences at, and during ramet establishment, and subsequent growth.

- It is recommended that everbearer chilling be carried out in an unheated polythene tunnel, which is the most economic and the industry's current practice.

SCIENCE SECTION

INTRODUCTION

The overall aim of the project was to provide the scientific basis necessary for the development of a soil-less strawberry growing system for the UK, which is sustainable, environmentally responsible and cost effective. The system would be cropped continuously over an extended season (May – September) and yield over 50 t/ha of Class 1 fruit.

To achieve these aims, the consortium decided to employ the scientists to address four key areas of research:

1. The response of the strawberry plant to its water, light and thermal environments
2. Understanding resource partitioning between vegetative and reproductive growth, and the effects of partitioning on fruit production, quality and flavour
3. Alternative, soil-less substrates to peat, and their management
4. Factors affecting plant quality before planting

These were re-worded and designated as Scientific Objectives under which this science section is reported.

At present, it is estimated that less than 10% of strawberries produced in the UK are grown in soil-less substrates. The volumes produced outside of field soils have remained largely static over the past 5 years. Given the continued availability of methyl bromide and other soil sterilants, the majority of growers have found it more cost effective to continue growing in the soil. One reason for this is that they have attained yields from the soil which are equal to or better than those in soil-less substrates while they incur lower costs of production.

However, the phased withdrawal of methyl bromide from use in the UK will undoubtedly force many growers to look for alternative production systems as the loss of this soil sterilant will lead to a reduction in yields from field soil plantations. If growers are to turn to soil-less substrates, they will need a system of production, which will offer high yields of fruit from an extended

season of production. In addition, the quality and flavour of the fruit will need to be equal to, or better than, that produced from field soils. However, firstly they will need a sustainable substrate in which to develop an optimum production system.

The majority of those growers who already produce strawberries in soil-less substrates use peat, while a smaller number of growers use coconut fibre (Coir). However, there is only a finite source of both of these commodities in the world and neither were deemed by the consortium to offer a sustainable resource or substrate for the long-term future. Indeed, the UK government has introduced biodiversity targets related to protection of certain types of habitat such as lowland raised peat bogs. There are targets for 40% of all horticultural use of soil improvers and growing media to be composed of non-peat materials by 2005, and 90% replacement of peat by 2010. The consortium therefore decided that a part of this project should aim to identify alternative substrates to peat (under Objective 3) for growing strawberries in. Subsequent work would refine the irrigation and nutrient delivery systems required for the chosen substrates.

To develop an optimum production system, work was conducted on the two principal varieties in the UK, Elsanta (a short-day variety) and Everest (a day-neutral or everbearing variety). Short day varieties like Elsanta initiate flowers in response to shortening day length (autumn in the UK), while day-neutral or everbearing varieties like Everest initiate flowers throughout the year, irrespective of daylength.

To achieve continuous cropping and a high yield over an extended season, the consortium decided to study means of manipulating Elsanta and Everest to both extend the period of flower production and optimise the quality of flowers and subsequent fruits.

In the case of Elsanta, the consortium wished to ascertain whether season extension using a combination of basic environmental prompts (both prior to and after planting) could be commercially viable. They assessed (under Objective 4) the effect of different combinations of both cold storage temperature and duration to give varying degrees of chilling according to a previously described chill unit model. This was done in association with the use of artificial long-

days (night break lighting) and field chilling. It was hoped that this work would identify ways of manipulating Elsanta to produce a continuous cropping season.

In the case of Everest, the consortium also considered it necessary to determine the effects of chilling on plants prior to planting and establishment as well as the potential influence of the original position of plantlets on the stolon produced by mother plants in propagation stocks. This work was also undertaken as part of Objective 4, with the intention of identifying ways of maximising the cropping potential of these varieties and to achieve season extension.

However, in addition to pre-planting chilling treatments with Everest, the consortium also wished to experiment (under Objective 1) with different light and temperature regimes to ensure that they could optimise the numbers of flowers produced over an extended period and ensure that this resulted in an optimum yield. They already knew that the influence of the environment on balance of assimilate partitioning between vegetative and reproductive growth is of particular importance for optimised long-season production (Camacaro *et al.*, 2002). It was decided to assess the effect of photoperiod on flowering and the response of Everest to shade. It was also decided to establish the optimum temperature for fruiting, whilst at the same time examining the effect of day and night temperatures to find ways of preventing thermodormancy, which prevents flowers from being produced. Further understanding in these areas would lead to the development of a growth model for Everest, allowing the industry to identify ways of manipulating the variety to extend the season of production and increase yield.

To ensure that the system produces high yields of high quality fruit making it sustainable and cost effective, the consortium felt it necessary to study fruit production, quality and flavour. This would be done both by assessing the effect of inducing plant water stress and examining its effect on yield and flavour (under Objective 1) and also by providing a quantitative description of resource partitioning between vegetative and reproductive growth (under Objective 2).

Under Objective 1, the work to induce water stress on Elsanta and Everest grown in soil-less substrates would be expected to lead to increased sugar levels, but would also provide additional assimilates for the production of secondary flavour compounds, notably acids and fruit flavour

volatiles. Experiments were set up to develop a novel electronic system for controlling water stress in peat bag grown strawberry crops. Further experiments were set up to investigate the development of analytical techniques to measure the biochemical components of strawberry fruit flavour. Subsequent work was conducted using these analytical techniques to investigate the influence of controlled water stress on fruit flavour. This work aimed to identify ways of improving the control of both yield and fruit flavour/quality by improving the control of water relations in the plant.

Under Objective 2, initial work was done to identify the key volatiles producing the perceived strawberry flavour. Further work was conducted to determine the influence of sink strength (achieved by flower thinning) and source strength (achieved by canopy shading) on fruit flavour quality in Elsanta and Everest. Experiments were also conducted with no flower thinning and also to investigate the effect of fruit shading on flavour. In all of this work, both trained and un-trained taste panels were employed to assess the flavour. This work aimed to identify ways of manipulating the source/sink relationship within the plant to improve yield and fruit quality.

SCIENCE SECTION

OBJECTIVE 1

Define the Responses of the Strawberry Plant to its Water, Light and Thermal Environments

General Introduction

For the development of an optimised long-season strawberry cropping system, a deeper understanding of the responses of the strawberry plant to its water, light and thermal environments was sought in eight experiments conducted within Objective 1. The aim of experiments 1 to 4 was to define the responses of the strawberry plant to its water environment, and of experiments 5 to 8 to define the responses of the strawberry plant to its light and thermal environments.

Systems in which long-season production is achieved by means of a range of short-day and everbearer/day-neutral cultivars with overlapping seasons are reported to be more economical than those in which the cropping period of a single short-day cultivar is manipulated (Simpson *et al*., 1997). The cropping potential of everbearing strawberries is much higher than that of Junebearers (Camacaro *et al*., 2002), and although poorer fruit quality has previously restricted everbearer marketability (Simpson, 1993), improvement in this area means that everbeareres are likely to increase steadily in importance. Work conducted here focused on the Junebearer 'Elsanta' and the everbearer 'Everest'. 'Everest' ('Evita' x 'Irvine') is one of two favoured everbearers in commercial production in the UK: 'Bolero' and 'Everest' between them account for approximately 90% of the UK everbearer production area (Taylor and Simpson, 2001).

Responses of the Strawberry Plant to its Water Environment

Controlled water stress applied during fruit development has been used in a number of crops to improve fruit flavour. The influence of such water stress seems to be due to root signalling

causing diversion of assimilates to developing fruits. This would be expected to lead to increased fruit sugar levels but would also provide additional assimilates for the production of secondary flavour compounds, notably acids and fruit flavour volatiles. A number of problems are associated with using water stress for fruit flavour manipulation. For example, such techniques can only be used where plant water needs are provided by irrigation. There is also the physical problem of managing soil water potentials under rapidly changing environments, and finally any water stress may lead to an unacceptable yield loss.

A number of experiments on 'Elsanta' and 'Everest' were used to investigate the use of controlled water stress. Experiment 1 involved the development of an electronic system for the control of water stress. Experiment 2 was a preliminary investigation developing analytical techniques to measure the biochemical components of strawberry fruit flavour. Experiments 3 and 4 used these analytical techniques to investigate the influence of controlled water stress on fruit flavour.

Responses of the Strawberry Plant to its Light and Thermal Environment

Little is known about the temperature and light requirements for optimum fruit production in 'Everest'. The developmental patterns through the season have previously been compared for outdoor crops of 'Bolero', 'Everest' and 'Elsanta', and the capacity for prolonged production of the everbearers quantified. In contrast to Junebearers, the prolonged season of everbearers causes vegetative growth and fruiting to coincide (Camacaro *et al*., 2002), so the influence of the environment on the balance of assimilate partitioning between vegetative and reproductive growth is of particular importance for optimised long-season production. Experiments 5 and 6 concentrated on the response of 'Everest' to shade, and on systematically establishing the temperature optimum for fruiting; they also provided an analysis of the interaction between growth environment and resource distribution. Temperature controlled glasshouse compartments were used to provide set-point temperatures of 10, 14, 18, 22, 26 and 30^{o}C.

Periods of high temperatures mid-season were found to result in heat induced cropping troughs, referred to as thermo-dormancy. The sensitivity to periods of high temperature exposure and the

relevance of day/ night temperature integrals were examined in detailed transfer treatments in experiments 7 and 8. This work confirmed the central role of high night temperatures in triggering thermo-dormancy.

The effect of photoperiod on flowering was also investigated in experiments 5 and 6, because of the need to understand the effect of seasonal change in light environment on flower initiation in everbearers. Previous research of the effects of photoperiod and temperature has tended to focus on Junebearing varieties because of their commercial dominance (Le Mière *et al*., 1996, 1998).

Shade tolerance is a consistent feature of strawberry species and cultivars. The response to light integral has been reported for the woodland strawberry *Fragaria vesca* (Jurik and Chabot, 1986), as well as for commercially grown 'Hapil' (Wright and Sandrang, 1995), 'Rapella' (Awang and Atherton, 1995) and most recently 'Elsanta' (Fletcher *et al*., 2002). A main feature of shade tolerance found here for 'Everest' was the increase in leaf area per unit leaf weight (experiments 5 and 6). A specific experiment in year three examined the possibility of exploiting this increase in source capacity in 'Everest' by shading plants prior to fruit production (experiment 7).

OBJECTIVE 1 EXPERIMENTS

Define the Responses of the Strawberry Plant to its Water Environment

Key results are presented and discussed for experiments 1 to 8, and the annual or interim reports are referred to, for further details, where appropriate.

Experiment 1 Development of an Electronic System for Controlled Water Stress (Task 1.1)

Introduction

A series of techniques was developed and demonstrated to monitor plant transpiration and media water content, to enable irrigation to be applied automatically and to monitor plant water stress. This work has been reported previously in the annual reports for years 1 and 3.

Materials and Methods

Weighing System for Transpiration Monitoring and Irrigation Control

ADAS collaborated with instrument manufacturer Sensatech to develop a computer-controlled weighing device for monitoring plant transpiration and media water content and to enable irrigation to be applied automatically. The initial requirement was for a machine capable of monitoring the weight of plants grown in a 50 cm × 20 cm 'grow-bag' system to a maximum value of 6kg within 20g accuracy and with a digital electronic output.

The method devised was to mount a weighing platform (64 cm × 32 cm) on four simple corner springs above a base plate, so that the gap between platform and the base plate varied with the applied load. The gap formed the dielectric layer of an electrical capacitor. Thus measuring the

value of this capacitor enabled the weight to be deduced. A theoretical model was constructed to aid the design of a device with a linear range up to 8 kg required for the strawberry grow-bags.

An electronic circuit, developed by Sensatech, was incorporated into each weighing platform for sensor excitation, signal capture and signal conditioning. A device was also incorporated for monitoring the temperature of the weighing platform and a method was devised for compensating for the effects of temperature on the circuit components.

The weighing platforms were provided with digital communication links to a central microcomputer. The system also carried a 5 volt controllable signal from the computer that was used for switching individual irrigation pumps via a relay.

A computer programme was written by Sensatech for displaying and recording the weight measurements, calculating irrigation requirement according to adjustable set-points, and providing output signals to activate electrical relays delivering power to the water pumps.

Irrigation was separately controlled for each grow-bag and applied using a peristaltic pump mounted next to each weighing platform. Each pump was fitted with a 'normally-closed' electronic relay that switched power to the pump for the duration of a 5 volt signal controlled by the computer software. Thus the timing and the amount of irrigation applied could be automatically programmed, based on measured water use by the plants and the estimated media water content.

Instrumentation for Direct Measurement of Soil Moisture Content

Two commercially available soil moisture sensors, the Campbell Scientific TDR probe and the Delta-T devices *Theta* probe were evaluated for use in peat-media grow bags. The TDR probe was supplied for use with a Campbell Scientific data logger, so it was modified by ADAS to enable stand-alone, hand-held measurements. This involved developing electronics for signal conditioning and display, consisting of a frequency-to-voltage converter, a digital display, a rechargeable battery pack and rugged casing.

Stem Thickness Measurement to Assess Plant Water Stress

Previous work by many researchers has demonstrated that measurement of stem thickness provides a valuable and sensitive indicator of plant water stress. The challenge was to make a device that was suitable for use in commercial crops where the requirement would be low-cost and simplicity of use.

One of the most cost-effective instruments for continuous measurement of stem thickness is Sensagap non-contacting position sensor model no SG5 (RDP Electronics). It works by detecting a change in electrical capacitance and these measurements may be affected by variations in tissue water content, potentially resulting in errors.

Apparatus was constructed to enable a low-cost Sensagap to be used to detect the movement of a weak metal spring clamped to the strawberry runner so that measurements could be used to track changes in tissue thickness.

Measurements using the apparatus were calibrated using shims of known thickness in the range 1-4 mm. A possible error due to temperature fluctuations (0.02% of range according to manufacturers' literature) was tested by monitoring the output of the sensor in an uncontrolled greenhouse. Continuous measurements on strawberry plants were made to confirm that variations in runner thickness were consistent with the expected effects of diurnal fluctuations in the environment on plant water stress and with increases due to plant growth.

Infra-red Thermometry (IRT) Leaf Stress Index Method

The IRT method involves, essentially, pointing a hand-held device at an individual leaf to measure its temperature while simultaneously measuring temperatures in two reference surfaces, one wet and one dry. A relationship between these measurements provides a stress index value between 0 (zero stress) to 1 (extreme stress).

The infra red sensor used was a Convir EL 101A series and associated 24V power supply (Calex Electronics Limited, Leighton Buzzard) providing a current output of 20 mA for a temperature range 0-250 ^{0}C. This sensor had a nominal spot diameter to sensor /object distance of 10:1 which was suitable for targeting a crop row when the sensor was mounted on a glasshouse roof structure (Figure 1).

For the reference surfaces, previous work indicated that the closest thermal match to plant tissues is obtained using stainless steel sheet (AISA 304) and for strawberry leaves, a suitable thickness was 0.5mm. Sheets were cut to be slightly wider than the diameter of a Whatman filter paper (>12.5 cm). Rapid response type T thermocouples were formed, by twisting together a pair of thin constantan and copper wires (0.1mm diameter) and the junction was soldered to the centre of the steel reference surface. Each trailing lead was then sheathed with plastic and connected through an 'in-line' socket /plug (RS component nos. 219-4876 and 219-4882) to a thicker type T cable for connection to the data logger. Plastic rods were then bolted to each sheet to act as (low thermal conductivity) holding arms.

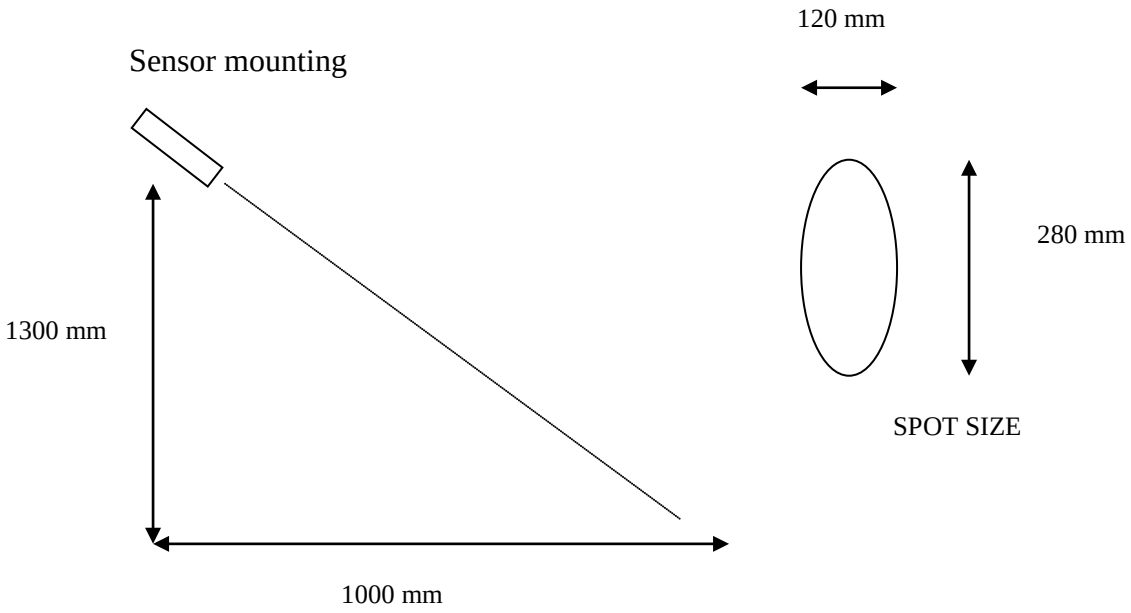

Figure 1. Sensor mounting and resulting IR spot size at the crop canopy height.

Whatman no 2 filter papers were dyed green using 'Draylon tartan green' as per manufacturer's instructions except that disks were dipped for 10s in the dye solution, dried then dipped again to

achieve approximate matching of shade with strawberry plant leaves. The wet reference surface was simply formed by placing a wetted filter disk onto the surface of the instrumented steel sheet. The dry reference surface was treated identically to the wet reference except that the wet filter paper was then covered with Melenix film and sealed using clear silicone sealant. The reference surfaces were mounted horizontally in the upper canopy of the strawberry crop.

The output from the IR sensor and reference surface thermocouples were measured each minute and averaged over 10 minutes for storage by the data logger.

Results and Discussion

Weighing System for Transpiration Monitoring and Irrigation Control

A prototype computer-controlled weighing device for monitoring plant transpiration and media water content and to enable irrigation to be applied automatically, was successfully demonstrated. It was shown that, in principle, this type of system could be used in commercial production if required by the industry. Such a system could be used to monitor water use in a few typical bags within a large production area, and the electronic output used to control the irrigation to all the bags within the production unit. This type of system may become of value to the industry when there is a need or desire to decrease bag run-off, to limit ground water pollution and use of water. An alternative approach would be to recycle the solution that runs through the bag, but this is likely to be more costly.

Instrumentation for Direct Measurement of Soil Moisture Content

Readings with both the Campbell Scientific TDR probe and the Delta T Devices probe were highly correlated with independent measurements of volumetric moisture content of the compost media. For the TDR probe the best fit was obtained using a logarithmic transformation. This could be explained by a non-linearity in the frequency to voltage conversion at the extremes of range, which could be modified to a small extent by electronic circuit adjustments. However, the

probe could not be used to discriminate between differences in moisture content at the very end of the range (> 0.55 v/v). For the *Theta* probe, measurements using the in-built organic calibration setting produced a linear, though non-unity fit with moisture content, indicating that probe accuracy could be improved by modifying the calibration setting.

Measurements with a TDR soil moisture probe were compared with gravimetric measurements in bags that were allowed to slowly dry out for calibration. These measurements showed that the same calibration curve could be fitted to each medium (Figure 2).

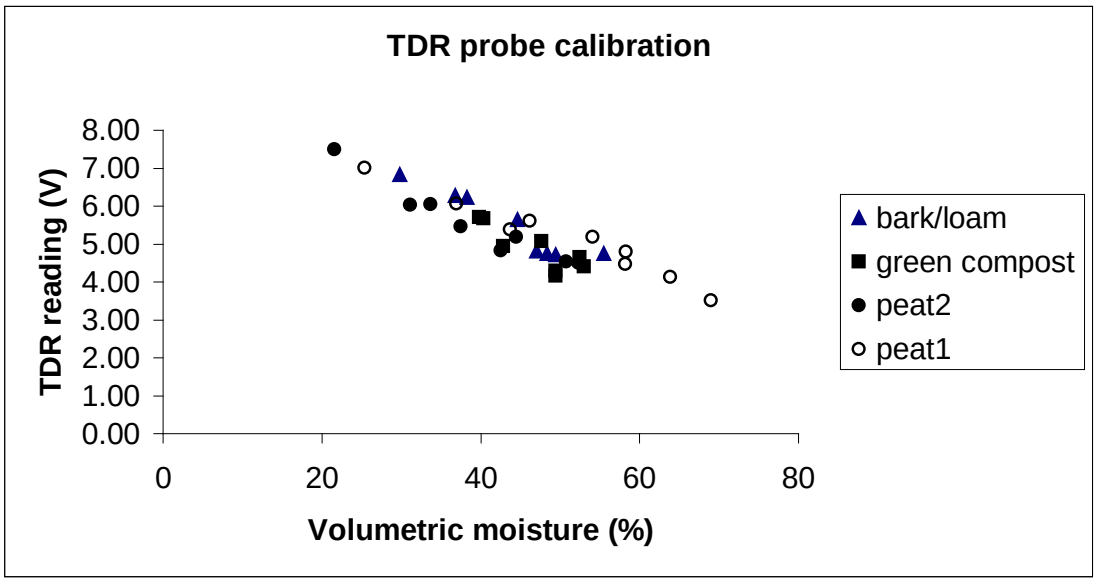

Figure 2. Results of all TDR probe measurements and corresponding moisture content for all three media with two separate drying cycles for the peat media. A fitted linear relationship from this data used to calibrate TDR measurements had a slope of TDR x –8.70511 +88.6227.

The TDR probe had an apparently lower precision (R^2 value) compared with the theta probe. This was partly due to differences in the methods used for determining media moisture content. The length of the TDR probe (30cm) meant that it sampled a larger volume of compost and consequently included errors due to moisture gradients within the grow-bag that inevitably occur in commercial growing environments. The shorter (10cm) Theta probe, enabled comparisons to be made with samples taken directly from around the probe, thus reducing the moisture gradient problem for calibration purposes. In practice, however, the sample volume measured by the TDR

probe was more representative of the rooting environment than that measured by the Theta probe. The uncertainties caused by moisture gradients indicate that caution is required when interpreting measurements with either probe. This limits their usefulness in commercial growing systems based on media grow-bags.

IRT Method for Measurement of Plant Water Status

In two experiments, the variable aerial conditions precluded plant water stress measurements by the IR technique. Measurements were made with a fixed IR sensor pointed at the crop canopy rather than the previously tested method of using a hand-held IR sensor pointed at individual leaves. These showed that all canopy temperature measurements were cooler than corresponding measurements of individual leaves and wet reference surfaces, perhaps caused by mutual leaf shading. This precluded use of the stress index formula and suggested further work would be required to develop and test a suitable reference surface for use with canopy measurements.

Continuously Monitoring Plant Water Stress using a Sensagap Thickness Sensor

Stolon thickness measured using the apparatus varied diurnally, consistent with variations in plant water stress. The stolon thickness decreased after sunrise each day to reach a minimum around 1 pm, then increased again between late afternoon and 8 am the following morning. The measurements were highly correlated with corresponding variations in atmospheric humidity and temperature. Measurements (Figure 3) made in the laboratory under conditions of steady temperature, confirmed a highly linear relationship between stolon thickness and plant water potential measured with a dewpoint psychrometer technique (McBurney 1988). Surprisingly, no increases in stolon thickness due to plant growth were found, so that the variations were almost entirely accounted for by changes in evaporative demand.

A method was developed previously for continuously monitoring plant water stress indirectly, based on the use of an electronic linear variable displacement transducer (LVDT) for measuring small changes in thickness of stem, petiole or leaf (McBurney 1994). Costs of LVDT's have precluded measurements in more than a just a few plants, making them unsuitable for

applications in commercial horticulture. Modern proximity sensing devices are considerably cheaper than LVDT's but their use in plant water stress measurements has not been developed. One of the most cost-effective instruments for continuous measurement of stem thickness is Sensagap non-contacting position sensor model no SG5 (RDP Electronics). It works by detecting a change in electrical capacitance and these measurements may be affected by variations in tissue water content, potentially resulting in errors.

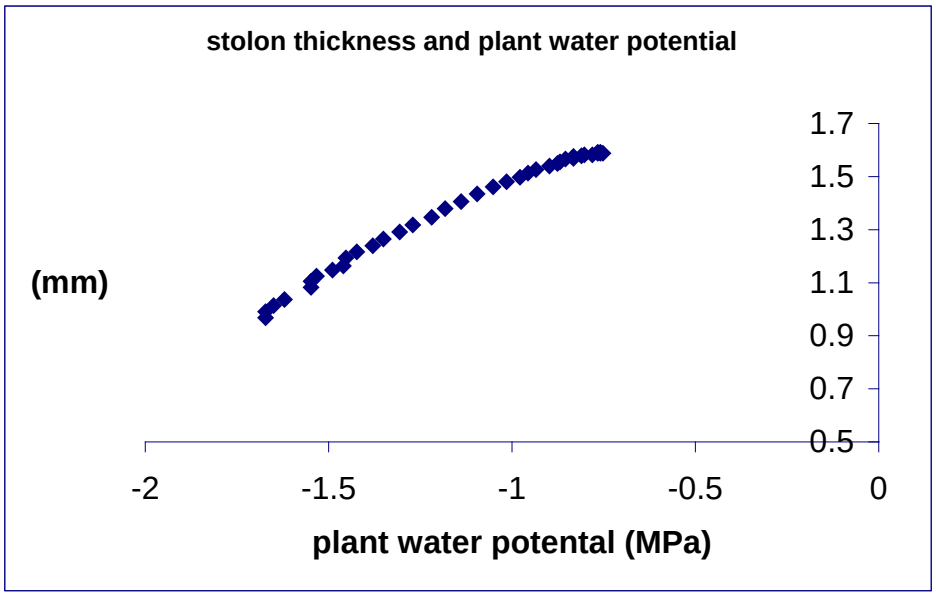

Figure 3. Example relationship between plant water potential, measured with a wescor dewpoint psychrometer attached to the stolon, and stolon thickness measured with the novel apparatus and Sensagap proximity sensor. All measurements were taken on a single stolon excised from the plant and allowed to dehydrate slowly overnight.

Experiment 2) Define a Flavour Profile for cvs. Elsanta and Everest (Task 1.3) and Relate Flavour Components to Flavour Profile (Task 1.4)

Introduction

Tasks 1.3 and 1.4 will be discussed jointly as they are based on one experiment conducted in year 1 by The University of Nottingham and ADAS Rosemaund.

Materials and Methods

The full report of this experiment can be found under Tasks 1.3 and 1.4 in the year 1_annual report and year 2 interim report.

Source of Fruit

The fruit used for initial flavour analysis was collected from the fully irrigated treatment of experiment 3 looking at the influence of controlled water stress on fruit flavour expression. Additional fruit was obtained locally; 'Elsanta' from Starkey (Southwell, Nottinghamshire) on 27/07/00 and 'Everest' from Tesco (Hinkley depot) on 05/09/00 and 27/09/00.

Flavour Analysis

Fruit volatiles were analysed using Atmospheric Pressure Chemical Ionisation-Gas Phase Analysis. Fruit of a similar size and ripeness stage (assessed by colour standards) were chosen. Before analysis the calyx was removed with a scalpel and each fruit cut in half. Each half was placed in a sealed vial, one half was frozen for later non-volatile analysis. The other half was placed in a blender and macerated. The headspace of the blender was sampled for 30s. To allow for comparison between runs the mass spectrometer was calibrated with an ethyl butyrate standard.

Non-volatile compounds were measured by direct liquid-mass spectroscopy. The previously frozen half berries were thawed and the liberated juice used to measure the amount of glucose/fructose, sucrose and citric acid.

Results and Discussion

Twenty volatile compounds were identified, fourteen preliminarily identified by mass and six unknown. (Table A). The volatiles were chosen as the ones that occurred in all samples and were regarded in the literature as important. Subsequent comparison of APCI results with GC-

MS revealed that the unknown compounds were made up of a mixture of esters of various proportions. A number of the initially identified compounds were revised following GC-MS analysis; for example Heptanone was found to be a mixture of branched C6 esters and ethyl methyl butyrate to be methyl hexanoate. With many of the volatile compounds there was considerable variation with date of harvest.

Table A. Volatile ions detected in the headspace of pulped 'Everest' and 'Elsanta' Strawberries.

Ion Mass	Compound
43.5	Unknown 1
45.3	Acetaldhyde
57.4	Unknown 2
59.2	Acetone
61.2	Acetic acid
71.4	Unknown 3
75.2	Methyl acetate
83.4	Unknown 4
89.3	Ethyl acetate
97.3	Unknown 5
99.3	Hexenal
101.2	Hexanal
103.2	Methyl butyrate
115.2	Heptanone
117.2	Ethyl butyrate
129.2	Unknown 6
131.2	Ethyl methyl butyrate
143.2	Furanone
145	Ethyl hexanoate
159.2	Ethyl methyl hexanoate

Sucrose, glucose/fructose (not separated as identical mass) and citric acid were identified in all samples tested. As with the volatile analysis there was considerable variation between harvest dates.

Similar compounds were identified from the commercially obtained fruit samples. Interestingly the 'Elsanta' from Starkey comprised of two batches one of which had been picked the previous day and held in cold store, the other which was picked on day of measurement. For many of the volatiles measured higher levels were recorded from the freshly picked fruit.

Some differences in flavour profile as defined by amounts of volatiles were found between 'Elsanta' and 'Everest'. Everest was found to have less acetone, less methyl acetate, less hexanal and slightly more ethyl acetate at later harvests.

The major finding of this section (Task 1.3 & 1.4) was the variability in flavour compounds between harvests, which has been confirmed in later experiments looking at the influence of water stress and the effects of light. While differences in flavour compounds can be distinguished between cultivars it was not possible to create a 'standard' flavour profile for a specific cultivar.

Experiment 3) Describe effects of controlled water stress on fruit flavour expression (Task 1.5)

Introduction

This experiment was conducted in year 1 by The University of Nottingham.

Materials and Methods

The full report of this experiment can be found under Task 1.5 in the year 1 annual report.

Plant Growth Conditions

The experiment was set up in the experimental glasshouse at The University of Nottingham, Sutton Bonington campus. Two strawberry cultivars were used; 'Elsanta' and 'Everest'. The plants were established in grow bags, five plants to a half grow bag. The 'Elsanta' were planted on 29/02/00 and 'Everest' on 17/03/00. The plants were arranged in a randomised block design with four replicates of each irrigation treatment. Irrigation was via a drip irrigation system and prior to water stress application all plants were irrigated daily to run off.

Experimental Treatments

Water stress was applied over a three-week period during early fruit development (25/04/00-15/05/00); full watering was resumed at the end of anthesis. Stress was achieved by withholding irrigation. Peat water content was measured daily using a theta probe with the aim of achieving the following water stress values:

Well watered	0.5-0.3 m^3 m^{-3}
Mild stress	0.3-02 m^3 m^{-3}
Severe stress	0.2 or below m^3 m^{-3}

Plant Growth and Yield

Plant growth (leaf number, flower number, canopy height) was recorded weekly and at the end of the experiment forty 'Elsanta' plants from each treatment were destructively harvested. Fruit was harvested throughout the experiment for yield assessment.

Flavour Analysis

Fruit flavour compounds were analysed on 17/05/00, 25/05/00, 30/05/00 and 06/06/00 for 'Elsanta' and on 17/05/00, 25/05/00 and 30/05/00 for 'Everest'. Volatiles were analysed using APCI and non volatile compounds by LC-MS (see year 1 annual report). A trained taste panel was used to assess fruit flavour (aroma, sweetness, acidity and strawberry) (see year 1 annual report).

Results and Discussion

Water Stress

The required stress levels were achieved after 4 days for mild stress and 7 days for severe stress in 'Elsanta', but it took 14 days to achieve similar stress conditions in 'Everest'.

At the end of the stress period each cultivar had a few ripe fruit meaning that the water stress had been applied during fruit growth.

Plant Growth and Yield

Severe stress reduced leaf number in both cultivars.

There was a trend for 'Elsanta,' to have fewer flowers under severe stress but this was not significant and no such trend was observed in 'Everest'. Water stress significantly reduced total fruit yield in and mean berry weight at the first harvest 'Elsanta' (Fig 4), this trend was less clear in 'Everest'.

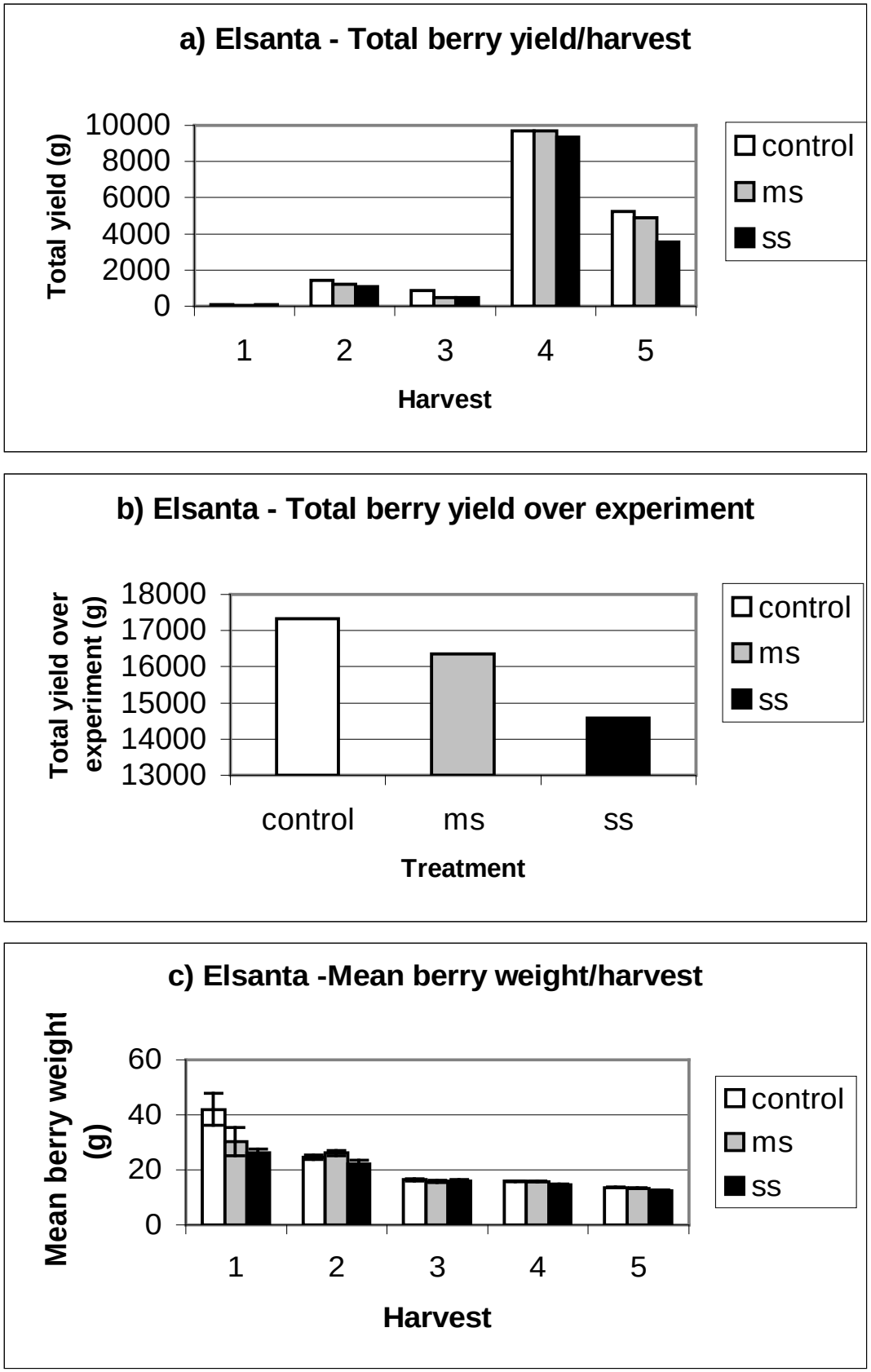

Figure 4**: Influence of water stress on a) Total 'Elsanta' berry yield per harvest, b) total 'Elsanta' berry yield over the experimental period, c) mean 'Elsanta' berry weight per harvest.**

The destructive harvest of ‘Elsanta’ showed that water stress significantly reduced total plant green area and that there was a trend towards a decrease in total dry weight.

Flavour Analysis

In both cultivars harvest date had a very significant influence on the amount of volatile and non-volatiles produced. The effects were variable, for example in ‘Elsanta’ Ethyl methyl butyrate reached its maximum at harvest two, while methyl butyrate increased over time in ‘Everest’ (Fig 5).

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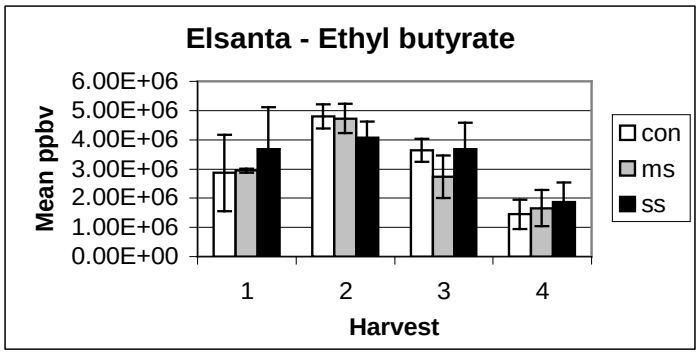

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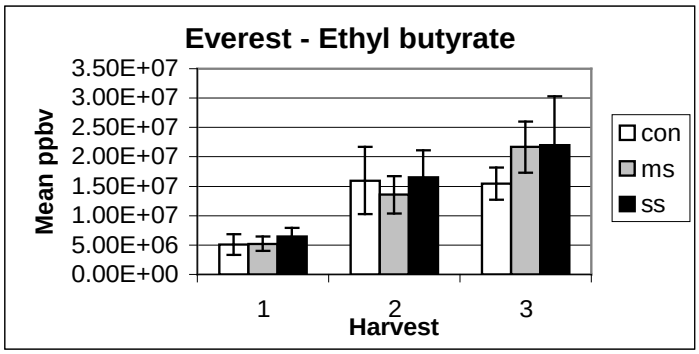

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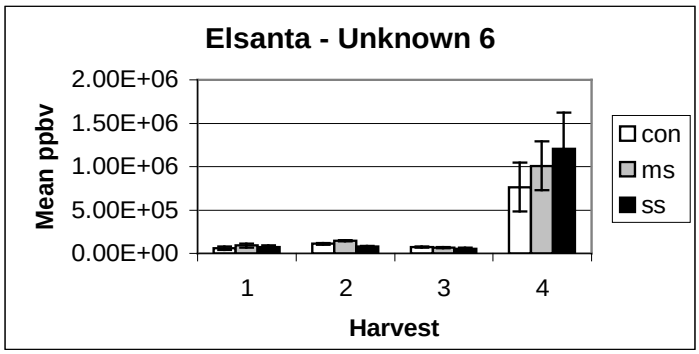

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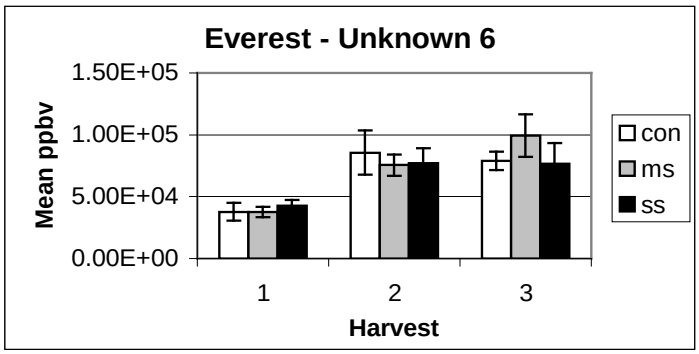

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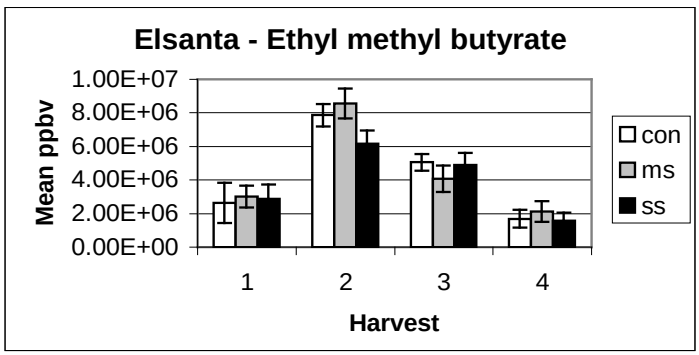

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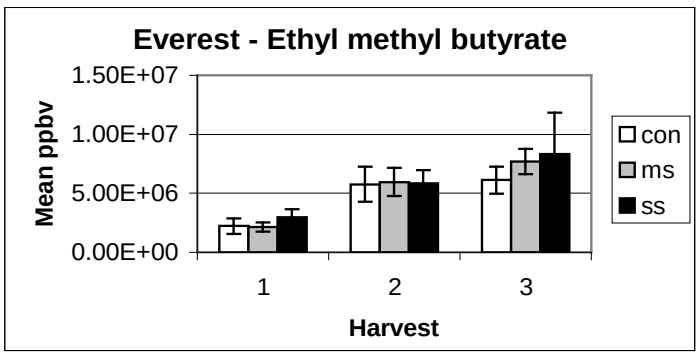
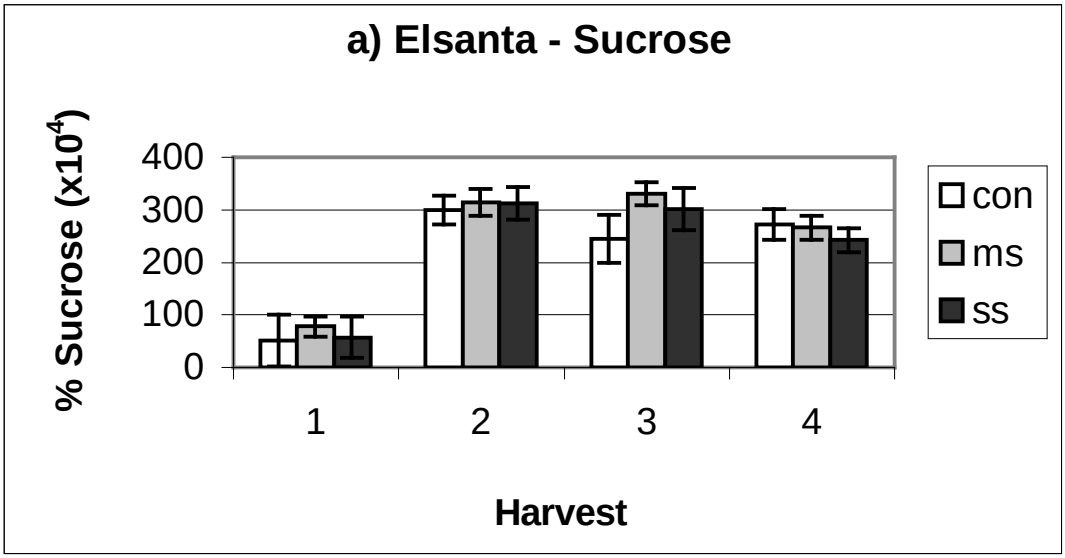
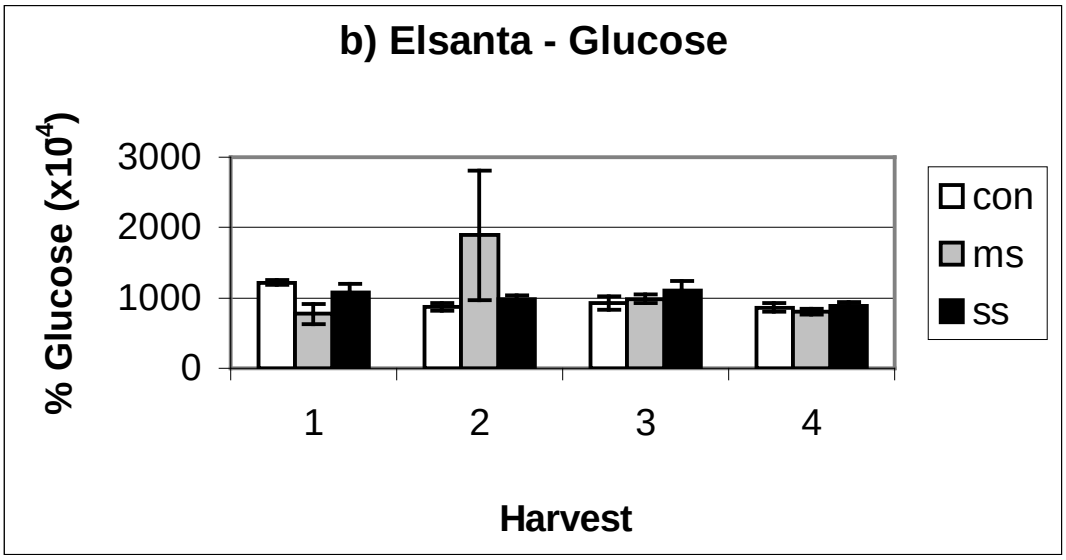


Figure 5: Influence Of Water Stress On Selected 'Elsanta' And 'Everest' Mean Volatile Concentrations Over Four Harvests. A) Ethyl Butyrate, B) Unknown 6, C) Ethyl Methyl Butyrate. I Represent 'Elsanta'; Ii Represent 'Everest'.

There was a trend for sucrose to increase over time in both cultivars, (Figure 6) however no effects of water stress were observed. The levels of glucose and citric acid showed no obvious trend with harvest date.





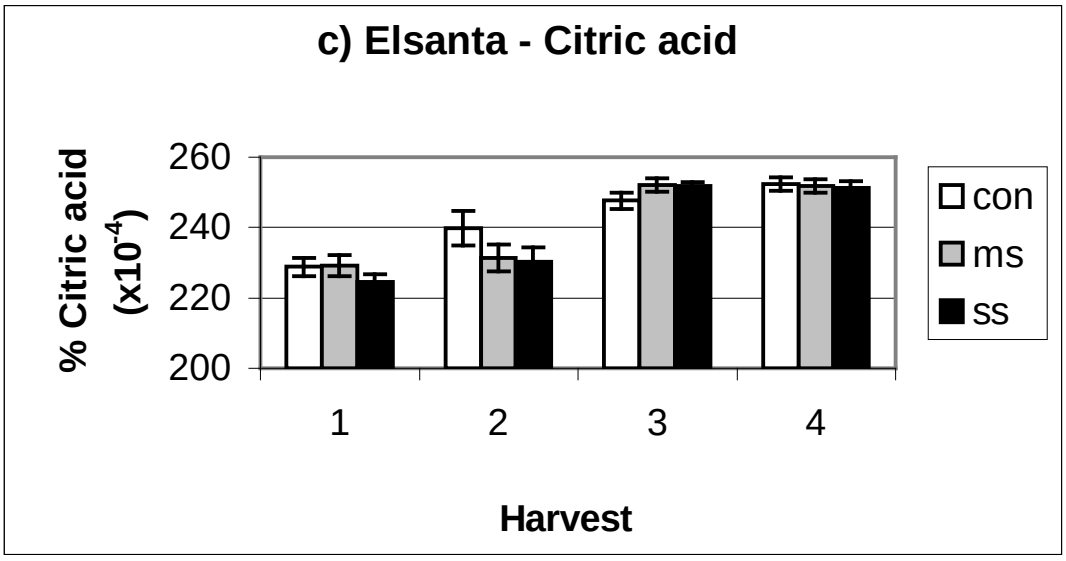


Figure 6: Influence of water stress on 'Elsanta' mean non-volatile concentrations over four harvests. A) sucrose, b) glucose, c) citric acid

There were no significant effects of water stress on flavour developments.

The taste panel found no effect of water stress in 'Elsanta,' however there was a slight effect of water stress in 'Everest' of increased berry sweetness.

Additional Experiment

A second experiment, looking at water stress applied at fruit ripening, was carried out at ADAS Rosemaund. Only 'Elsanta' were used in this experiment, water stress levels were similar to the first experiment but water stress was applied from 09/06/00 to 14/06/00 when fruit was ripening. Only non-volatile compounds were measured and no significant differences were observed.

Experiment 4) The use of Water Stress for Manipulating Fruit Quality (Task 1.8)

Introduction

This experiment was conducted in year 2 by The University of Nottingham and ADAS Rosemaund.

Materials and Methods

The full report of this experiment can be found under Task 1.8 in the year two annual report.

Plant Growth Conditions

The experiments were carried out at a commercial grower, Haygrove Farms. Two trials were carried out in commercial crops of 'Elsanta' one harvested in late spring/early summer the second harvested during the autumn. The plants were grown under normal commercial conditions. Experimental plots consisted of 10 grow bags for each treatment replicated three times.

Water Stress Treatments

Water stress was imposed by withholding irrigation to give: fully irrigated, moderate (35% media moisture) and severe (25% media moisture) stress. Stress was applied at the start of fruit picking and water withheld until the required media moisture content was reached after which normal irrigation was resumed.

Yield

Fruit was picked by farm staff and graded into class 1 and class 2 fruits. Total weight of each was recorded for each pick.

Flavour Analysis

In each experiment fruit samples were harvested just prior to water stress application and one week and two weeks after. These samples were analysed at Nottingham for volatile and non-volatile compounds. In addition 30 fruits from each treatment at each harvest were sent to M&S and Tesco for taste panel assessment.

Results and Discussion

The desired water stress was achieved after approximately six days (Figure 7) . It was interesting to note that there was considerable variation between individual bag water content even before the application of stress.

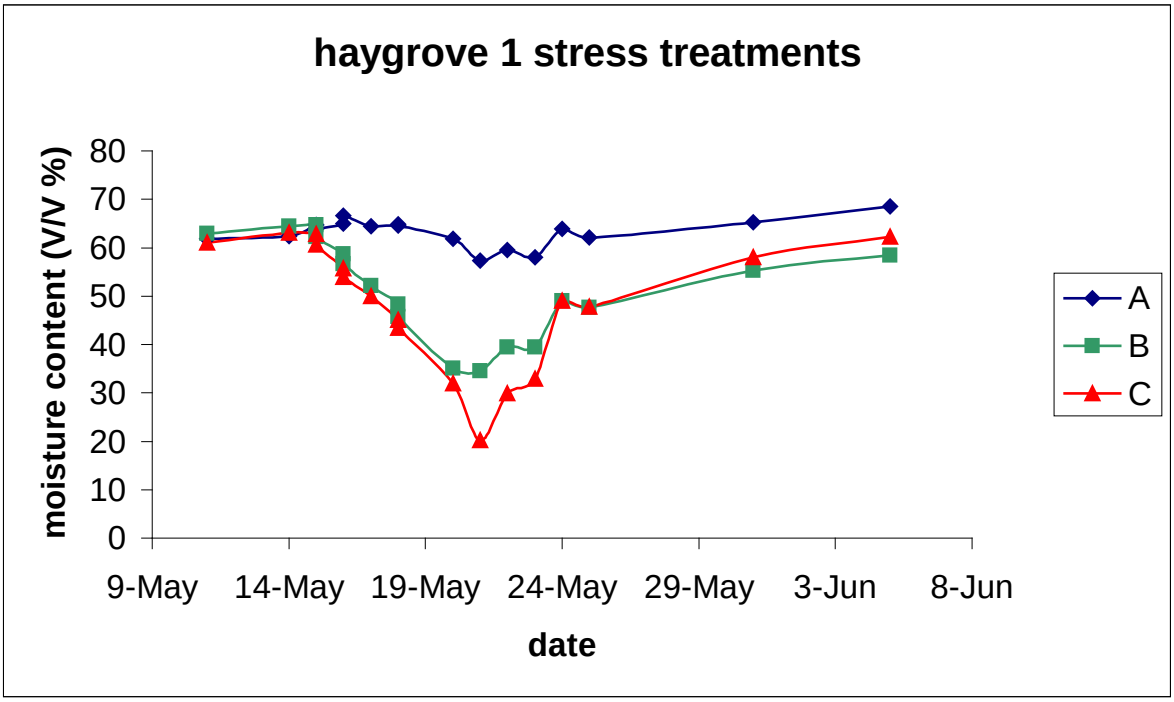


Figure 7. Media moisture content for the Haygrove 1 trial showing measurements for each stress treatment. A = no stress B= intermediate stress C = severe stress. Each point represents the average measurements in ninety peat media bags made with an adapted TDR probe. .

Water stress significantly reduced the yield of class 1 fruits at some harvests but the yield of class 2 fruits was unaffected.

There was no significant effect of water stress on non-volatile compounds.

There was an effect of water stress on some volatile compounds (e.g. ethyl acetate), which were reduced by water stress.

Taste panel scores tended to be high for both trials suggesting a generally good fruit flavour but no effects of water stress treatments were detected (Figure 8). This is perhaps not surprising as water stress had very little influence on the flavour compounds.

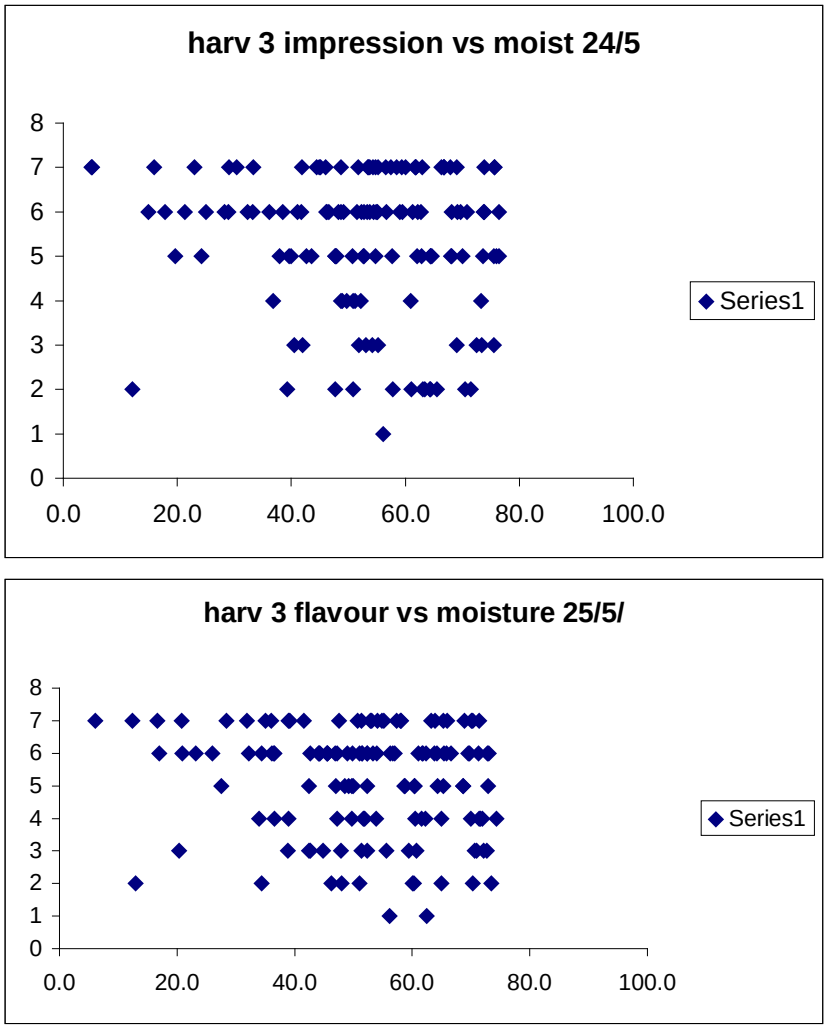


Figure 8. Selected taste panel scores for the final harvest (5 June) in the Haygrove 1 trial showing a plot of combined M&S and Tesco assessments for impression (top) and flavour (bottom) related to media moisture content measured on 25 may. Each point represents a single taster's score for an individual fruit. (moisture stress levels are V/V %)

OBJECTIVE 1 EXPERIMENTS

Define the Responses of the Strawberry Plant to its Light and Thermal Environment

Experiment 5) Optimisation of Everbearer Plant Performance for the System: Describe Effects of Environment on Everbearer Production. (Task 1.2)

Introduction

Information on the seasonal vegetative and reproductive development of the everbearer 'Everest' was gathered at the School of Plant Sciences, The University of Reading to underpin the development of an optimised, extended cropping system. The effects of the environment on everbearer production were measured in two glasshouse experiments conducted from 1st April to 30th of September 2000. In experiment 5.1, plants were grown at six set point temperatures between 10 and 30°C at two light integrals (ambient light and 50% shade). In experiment 5.2 plants were grown under 8, 11, 14 and 17 hour photoperiods with two 'night' temperatures (10°C and 20°C). The responses to temperature, light integral and photoperiod were monitored, and the environmental impact on flowering, fruiting and vegetative growth patterns was described. The objective was the quantification of everbearer 'Everest' responses to a range of environmental conditions.

Materials and Methods

Two experiments (5.1 and 5.2) were conducted in 2000 using a factorial glasshouse and a photoperiod facility at the School of Plant Sciences, The University of Reading. For experimental details refer to Annual Report 2000 and the Interim Report 2001. A summary is provided here.

Plants of the everbearing strawberry 'Everest' (tray plants supplied by Edward Vinson Ltd., Faversham, Kent) were planted in the second week of March into 2 l pots (ProGro, LBS, Lancashire) using strawberry peat bag compost (Westland Horticulture, Dungannon, N. Ireland) and placed in a glasshouse set at 18^{o}C and ambient light for two weeks to establish before being transferred to treatments on 1st April 2000.

An automatic irrigation system was used to supply nutrients to plants in the factorial compartments via 4l/hour pot drippers (Field Ltd., Appledore, Kent) on average eight times per day between 7 am and 9 pm. Irrigation to each of the six compartments was controlled manually so as not to cause over-watering in individual temperature treatments, as a consequence of the range of temperatures used. Nutrients (N, P, K, Mg, Ca, SO_4 and micronutrients Mn, B, Zn, Cu and Mo) were supplied using everbearer feed at a set point electrical conductivity of 1.5 mScm^{-1} and pH set at 5.9. The same feed solution was applied, as required, by hand to plants in the photoperiod treatments.

A destructive sample of three plants was taken every three weeks from each treatment from 1st April to 30th September. Parameters measured were crown number, petiole length (cm), leaf number, leaf area (cm^2), leaf fresh and dry weight (g), fruit number, fruit fresh weight and fruit dry weight (g). All measurements were taken per crown and summarised per whole plant. Fruits were harvested from six labelled plants in each of the treatments twice weekly. Temperature and light level were recorded every 30 seconds and hourly averages were stored by a data logger (DT500, Data Electronics, Welwyn Garden City). Pest control was carried out as required. In addition biological control of thrips was carried out using Amblyseius cucumeris (Novartis Crop Protection Ltd, Cambridge England). Statistical analyses were conducted using ANOVA procedures from the GENSTAT statistical computer programme (version 6).

Experiment 5.1 Six Temperatures at Two Light Integrals

Plants were placed on benches in the inner six compartments of a linear array of temperature-controlled glasshouse compartments (3.7 m x 7 m) set to provide minimum temperatures of 10, 14, 18, 22, 26 and 30^{o}C. The temperatures were allocated randomly within this linear array.

They were maintained by venting (air conditioning in the 10 and 14°C compartments) or heating, with venting occurring when the temperature rose 4°C above the set heating points.

The actual average seasonal temperatures were 10.9, 14.4, 19.1, 23.1, 25.5 and 31.2°C. The temperature treatments are referred to by these actual values forthwith. Fluctuations in temperature were largest in compartments without air conditioning at intermediate temperatures (18 and 22°C). Within each compartment one bench provided 30 plants with ambient light levels and a further covered bench (50% shading; 'Tildenet') provided 30 plants with reduced light levels:

11°C	Ambient light ---------- 50% shade
14°C	Ambient light ---------- 50% shade
19°C	Ambient light ---------- 50% shade
23°C	Ambient light ---------- 50% shade
26°C	Ambient light ---------- 50% shade
31°C	Ambient light ---------- 50% shade

Experiment 5.2 Four Photoperiods at Two Night Temperatures

Plants were placed on trolleys and maintained in a glasshouse at 17°C minimum temperature during the day (8am – 4pm) at ambient light. From 4pm – 8 am plants were transferred to a suite of eight, controlled environment photoperiod chambers for four day-lengths at two set point temperatures of 10°C and 20°C:

8 hour photoperiod	10°C night ---------- 20°C night
11 hour photoperiod	10°C night ---------- 20°C night
14 hour photoperiod	10°C night ---------- 20°C night
17 hour photoperiod	10°C night ---------- 20°C night

Day length extension was provided using a mixture of tungsten bulbs and fluorescent tubes.

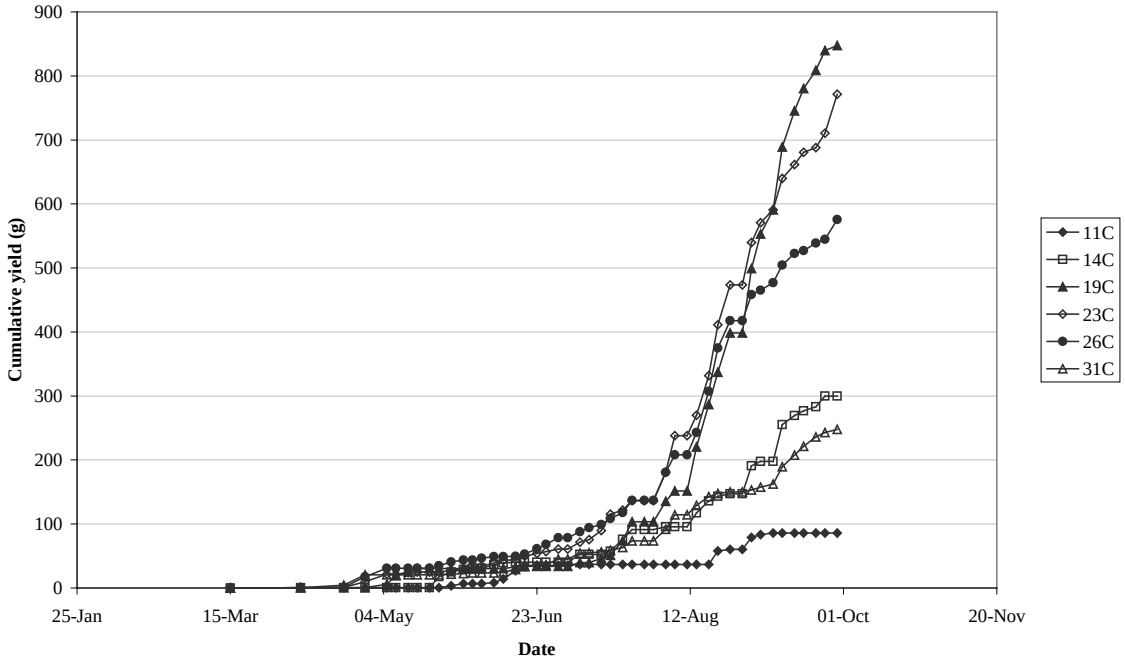
Results and Discussion

Experiment 5.1 Six Temperatures at Two Light Integrals

The highest yields were achieved at 19 and 23°C, with 847 g and 772 g per plant respectively (Figure 9a), in conjunction with the highest fruit quality (EC-specifications) at these temperatures. The lowest yields were given by the coolest (11°C) and warmest (31°C) temperatures with 86 g and 248 g per plant respectively. Steep increases in yield accumulation during August were found at 19, 23 and 26°C; these did not occur, however, by the remaining three temperature treatments.

50% shading significantly reduced crop yield throughout the temperature treatments (Figure 9b). An exception was at 14°C, where longer developmental stages may have allowed the plant to compensate for lower light intensities. Higher yields in unshaded treatments were due to greater fruit number, rather than larger individual berry weights. Low overall yields in this experiment were due to low air filled porosity of the compost, which reduced the drainage to the root system and prohibited optimal rooting (as analysed by ADAS).

a)



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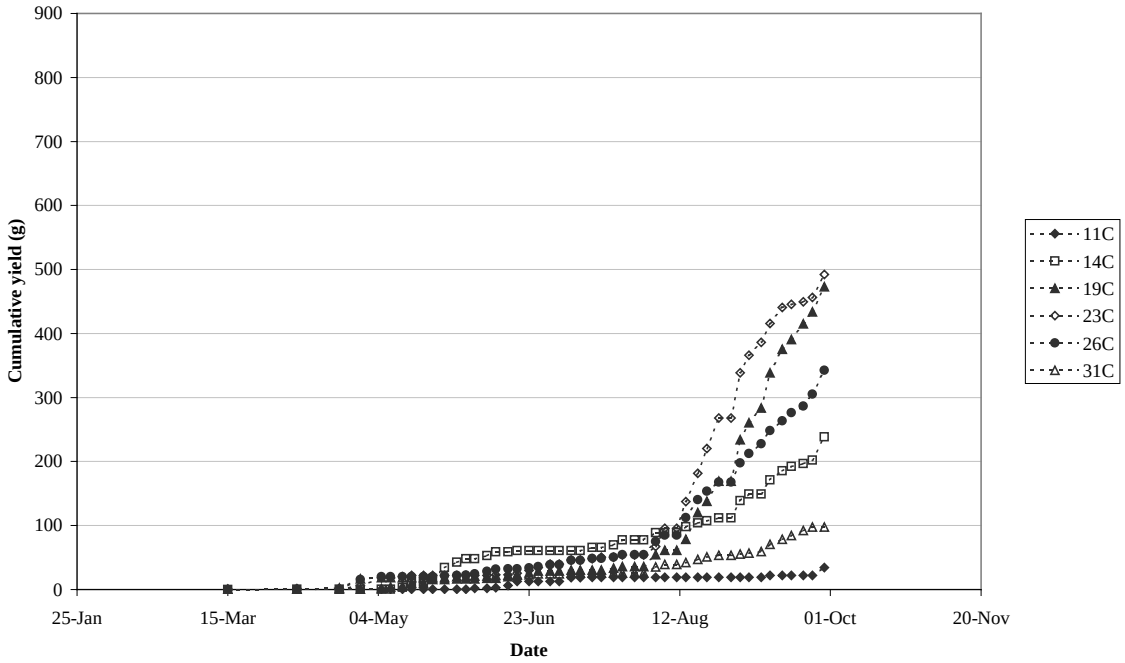


Figure 9. Cumulative yield (g), measured as fruit fresh weight per plant, between April and September 2000 at six different temperatures; a) at ambient light, b) under 50% shade.

By the end of September plants had produced greater above ground dry matter, if they had been grown at cool temperatures. This resulted in the highest plant dry weight of 94g per plant at 11°C and the lowest plant dry weight at 31°C with 19g per plant (Figure 5). Between the 26th June and the 18th September, however, a 14°C environment supported the largest plant dry matter. Growth at 14°C also resulted in the largest crown diameters and the largest leaf areas.

Some plants at high temperatures (26°C and 31°C) appeared to be overburdened with the energy requirements for fruit production (sink pressure), and died in August and September.

Single berry weight was greatest at 14°C and lowest at 31°C (data shown in the Annual Report 2000), but the harvest frequency was reduced at 14°C, as fruit required more time to ripen. A possible explanation was that plants grown at 14°C required more time for fruit development and assimilate partitioning between harvests. This meant these plants could photosynthesize for longer periods between harvests and accumulate more energy for biomass production to support the production of bigger fruit.

The implication of the above results is that the cropping season for plants at 14°C was longer. Plants grown at warmer temperatures came to the end of their cropping season earlier, while plants at 14°C were apparently able to sustain a longer cropping period, and provide greater overall yield. This hypothesis for a greater potential yield at 14°C was investigated by extending the cropping season in year two by one month (Task 1.7).

Experiment 5.2 Four Photoperiods at Two Night Temperatures

Petiole lengths were significantly affected by photoperiod, with longer petioles at 17 hours than at 8 hours, regardless of the temperature environment. Floral meristem initiation behaved differently, and was not significantly affected by either temperature or photoperiod. Throughout treatments the only significant factor influencing the number of floral meristems per plant was time. At the higher temperature the rate of flower abortion increased, resulting in a reduction of cropping. Closer inspection of this behaviour and the related problem of thermo-dormancy was conducted in experiments 7 and 8 (Task 1.9 and 1.11).

In summary, the main findings of experiments 5.1 and 5.2 were that 'Everest' initiates flowers irrespective of photoperiod, in a day-neutral manner, and that the balance of assimilate partitioning towards fruit is optimal at temperatures between 19 and 23^{o}C. Shade was found to ultimately reduce yield; the severity of this effect was dependent on the temperature environment. These findings were tested and validated in experiment 6 (Task 1.7).

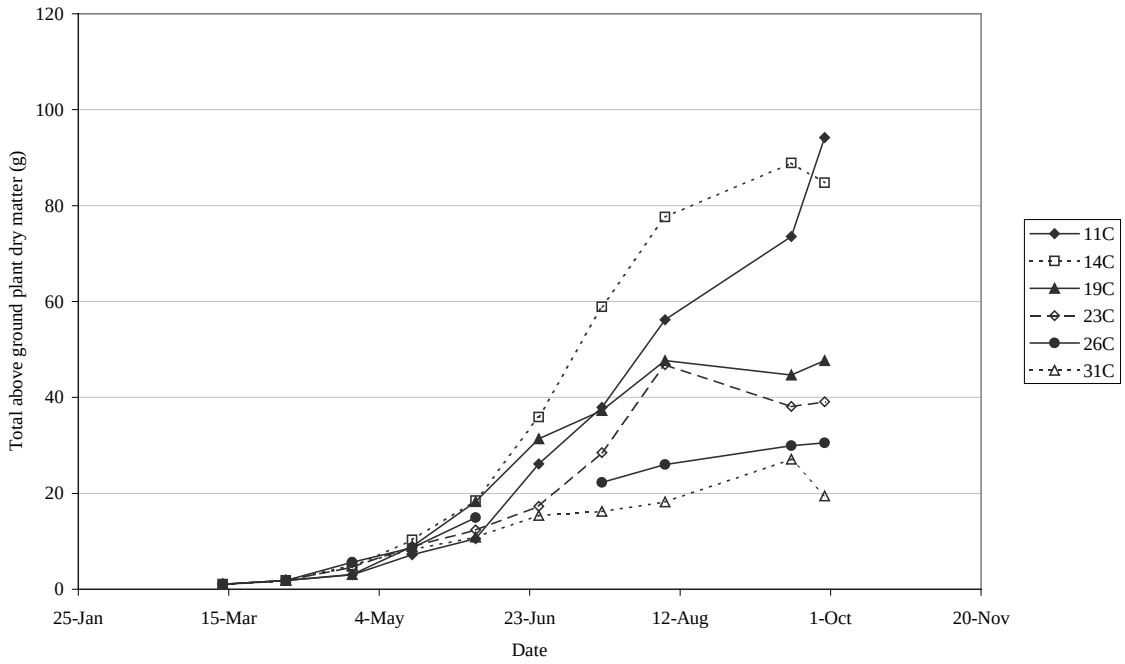


Figure 10. Total above ground plant dry matter (g) per plant between April and September 2000 at six different temperatures.

Experiment 6) Everbearer Production Model Testing: Test the Growth Model. (Task 1.7)

Introduction

Three experiments (6.1, 6.2 and 6.3) were conducted from April 1st to October 30th 2001 at The University of Reading, to study the effects of varying temperature, light, photoperiod and cultural

environments on the everbearing strawberry 'Everest'. Temperature treatments were applied for one month longer than in experiment 5 to explore the cropping capacity of plants at cooler temperatures, which were shown in year one to develop fruit more slowly.

The three experiments allowed a systematic approach to the analysis of patterns of resource partitioning during everbearer crop growth. This allowed the effects of environment during long season cropping to be tested and hypotheses to be developed on the basis for these effects; this in turn enabled more detailed experimentation in year three to investigate specific issues concerning everbearer crop growth (e.g. thermo-dormancy).

Materials and Methods

Three glasshouse experiments were conducted in 2001 at the School of Plant Sciences, The University of Reading. These experiments have been reported previously in the Annual Report 2001 and the Interim Report 2002, where details of methodology can be found.

Plants of the everbearing strawberry 'Everest' (tray plants supplied by Edward Vinson Ltd., Faversham, Kent) were planted in the second week of March into 2 l pots (ProGro, LBS, Lancashire) using strawberry peat bag compost (Westland Horticulture, Dungannon, N. Ireland) and placed in an unheated polytunnel for two weeks to establish before being transferred to treatments on 1st April 2001.

Plants were placed on benches in the inner four compartments of a linear array of temperature-controlled glasshouse compartments (3.7 m x 7 m) set to provide minimum temperatures of 14, 18, 22 and 26^{o}C. The temperatures were allocated randomly within this linear array. They were maintained by venting (air conditioning in the 14^{o}C compartment) or heating, with venting occurring when the temperature rose 4^{o}C above the set heating points. Within each compartment one bench provided 30 plants with ambient light levels and a further covered bench (50% shading; 'Tildenet') provided 30 plants with reduced light levels. An automatic irrigation system was used to supply nutrients to plants via 4l/hour pot drippers (Field Ltd., Appledore, Kent) on average eight times per day between 7 am and 9 pm. Irrigation to each of the six compartments

was controlled manually so as not to cause over-watering in individual temperature treatments, as a consequence of the range of temperatures used. Nutrients (N, P, K, Mg, Ca, SO_4 and micronutrients Mn, B, Zn, Cu and MO) were supplied using everbearer feed at a set point electrical conductivity of 1.5 $mScm^{-1}$ and pH set at 5.9. The same feed solution was applied, as required, by hand to plants in the photoperiod treatments.

A destructive sample of three plants was taken every four weeks from each treatment from 1st April to 30th October. Parameters measured were crown number, petiole length (cm), leaf number, leaf area (cm^2), leaf fresh and dry weight (g), fruit number, fruit fresh weight and fruit dry weight (g). All measurements were taken per crown and summarised per whole plant. Fruits were harvested from six labelled plants in each of the treatments twice weekly. Temperature and light level were recorded every 30 seconds and hourly averages were stored by a data logger (DT500, Data Electronics, Welwyn Garden City). Pest control was carried out as required. In addition biological control of thrips was carried out using *Amblyseius cucumeris* (Novartis Crop Protection Ltd, Cambridge).

The actual average seasonal temperatures were 14.9, 21.4, 23.1 and 26.8°C. The temperature treatments are referred to by these actual values forthwith. Fluctuations in temperature were largest in compartments without air conditioning at intermediate temperatures (21 and 23°C). Statistical analyses were conducted using ANOVA procedures from the GENSTAT statistical computer programme (version 6).

Experiment 6.1 Four Temperatures and Two Light Integrals

Plant growth and cropping patterns of 'Everest' were studied at four temperatures (15, 21, 23 and 27°C) and two light integrals (ambient light and 50% shade). Treatment start 1st April to experiment end 31st October 2001. The aim was to quantify everbearer (cv. Everest) plant responses towards a range of temperature and light conditions:

15°C	Ambient light ---------- 50% shade
21°C	Ambient light ---------- 50% shade
23°C	Ambient light ---------- 50% shade
27°C	Ambient light ---------- 50% shade

Experiment 6.2 *Growbag use, 25% Shade and Pinching Autumn Initiated Flowers in 'Everest' - Numerical Links for the Growth Model*

Within the quantification of everbearer 'Everest' plant responses towards a range of temperature and light conditions this data-set further aided the improvement of the growth model. It supplied numerical links for the differences in assimilate partitioning and overall productivity of plants grown in growbags as opposed to pots; of plants grown under 25% shade as opposed to ambient light; and of plants that did not have autumn initiated flowers pinched in spring as opposed to those that did:

Growbags at ambient light	vs.	Growbags at 25% shade
Growbags at ambient light	vs.	Pots at ambient light
Pots at ambient light	vs.	Pots with non-pinched plants at ambient light

The experiment consisted of four treatments at ambient glasshouse temperature with 9 labelled plants in each. A completely randomised design was applied, as recommended by the Statistical Advisory Service in the Department of Applied Statistics, The University of Reading.

Experiment 6.3 Photoperiod Experiment

A third experiment under Task 1.7 investigated flowering and growth patterns of 'Everest' at two photoperiods (8h and 14h) and two 'night' temperatures (10°C and 20°C), with the aim of testing and validating the year 2000 findings of flowering in 'Everest' to be daylength insensitive. Plants were placed on trolleys and maintained in a glasshouse at 17°C minimum temperature during the day (8am – 4pm) at ambient light. From 4pm – 8 am plants were transferred to a suite of four, controlled environment photoperiod chambers for two day-lengths at two set point temperatures of 10°C and 20°C:

8 hour photoperiod	10°C night ---------- 20°C night
17 hour photoperiod	10°C night ---------- 20°C night

Day length extension was provided using a mixture of tungsten bulbs and fluorescent tubes.

Crown dissections of three plants per treatment were conducted every three weeks to record the number of initiated flowers. A microscope of the type Wild Heerbrugg M3 Stereoscope, Switzerland, was used.

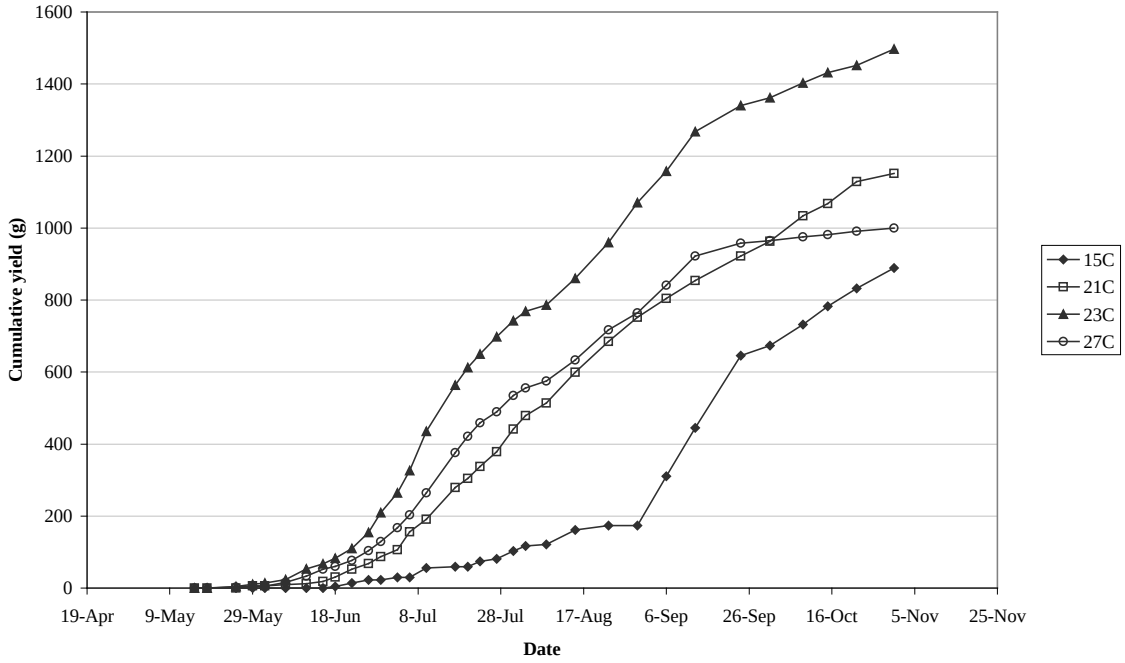
Results and Discussion

Four Temperatures and Two Light Integrals (6.1)

Total fruit yield increased up to 23°C and was significantly reduced under shade ($P < 0.05$). 50% shade reduced yields by 75, 34, 47 and 45% in the 15, 21, 23 and 27°C treatments respectively. The highest yield (1497 g) was found in the unshaded 23°C treatment, whereas its shaded counterpart only yielded 800 g (Figure 11b). A drop in production, possibly corresponding to 'thermo-dormancy', was observed between mid-July and mid-August in plants grown at 23 and 27°C. In both cases the production low followed peaks of high cropping loads (Figure 11).

The largest fruit number per plant was produced by plants grown at ambient light at 27^{o}C, with 199 berries per plant (Figure 12). Fruit yield peaked at 23^{o}C, whereas fruit number reached its maximum at 27^{o}C. This meant that more, smaller berries were produced at the highest temperature, indicating a capacity for yield compensation.

a)



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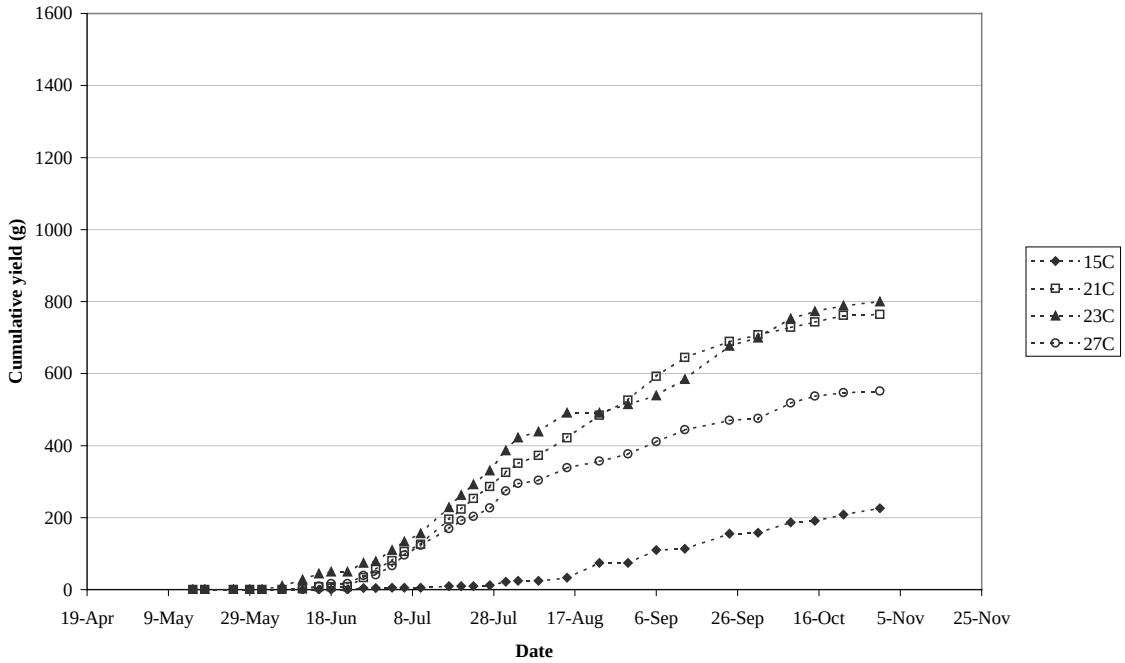


Figure 11. Cumulative yield (g), measured as fruit fresh weight per plant, between April and October 2001 at four different temperatures; a) at ambient light, b) under 50% shade.

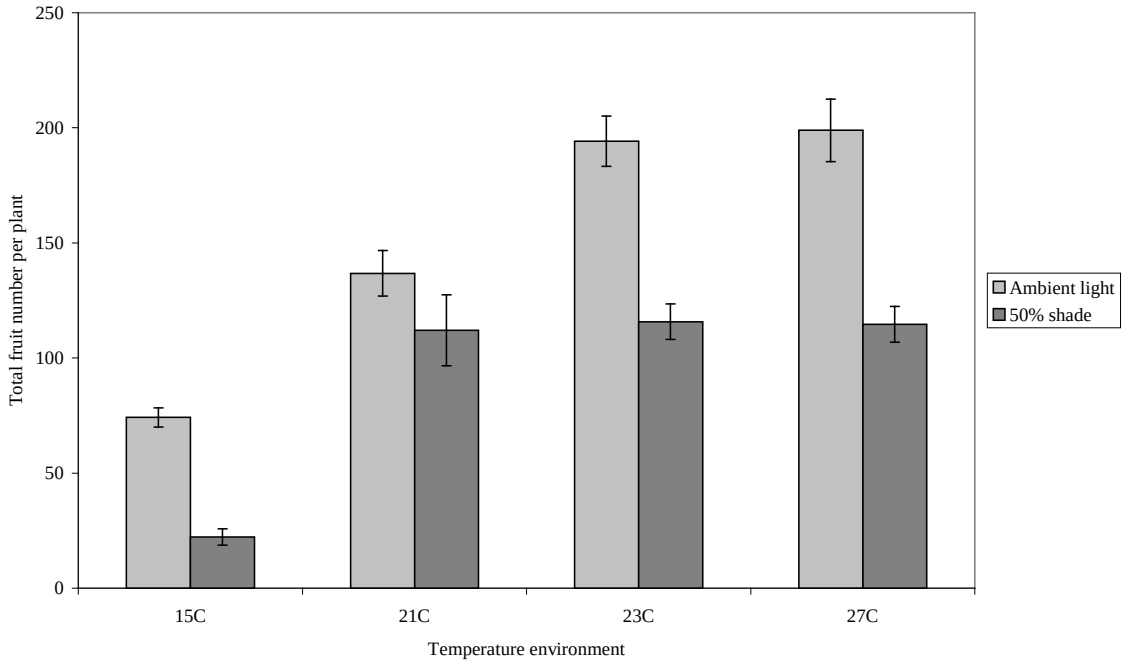


Figure 12. Total fruit number per plant, as affected by average temperature environment at ambient light levels and with 50% shade. Vertical bars ± SE.

The indication of a greater cropping capacity at cool temperatures (<19^{o}C), found in experiment 5, was tested by extending the season by one month. The 21^{o}C treatment in this experiment corresponds to the 19^{o}C treatment in experiment 5, sharing a set-point temperature of 18^{o}C. The seasonal variation between the two experiments caused the actual average of 19^{o}C in 2000 to increase to 21^{o}C in 2001.

The harvest index (HI), which is the fruit dry weight per total plant dry weight, was similar for temperature treatments of 21^{o}C and above, with an average HI of 64% by 1st October. At 15^{o}C, in comparison, the HI was significantly reduced, to 35%. This, in part, explains the low total fruit yield at 15^{o}C and shows that a season extension by one month does not result in a slower yet larger crop. This means that the cropping capacity at temperatures below 21^{o}C, even though vegetative growth is increased, is not larger.

In low light conditions assimilates began to be partitioned to fruit approximately three weeks later than at ambient light. 50% shade reduced the harvest indexes on 1st October by 10, 11 and 14% in the 21, 23 and 27°C treatments respectively. At 15°C, however, shade caused a drop of 49% in HI.

Leaves produced at later stages of growth were both smaller and thinner. Leaf weight ratio (LWR), which is the ratio of leaf dry weight to total above ground plant dry weight, declined linearly by approximately 20% over the season from the end of April. However, neither temperature nor light had an effect on LWR. The reduction in LWR in 'Everest' can therefore be described by one equation (slope) irrespective of light or temperature environment.

Leaf area ratio (LAR), the leaf area per unit above ground plant dry weight, also declined linearly over the season from May to October (Figure 13). Moreover, LAR was significantly greater under lower light conditions ($P < 0.01$), whereas temperature had no effect on LAR. This indicates that leaf area per unit above ground plant dry matter declined over the season by about 60 cm^2g^{-1} in the unshaded plants and by about 80cm^2g^{-1} in the shaded plants, in spite of increasing leaf numbers.

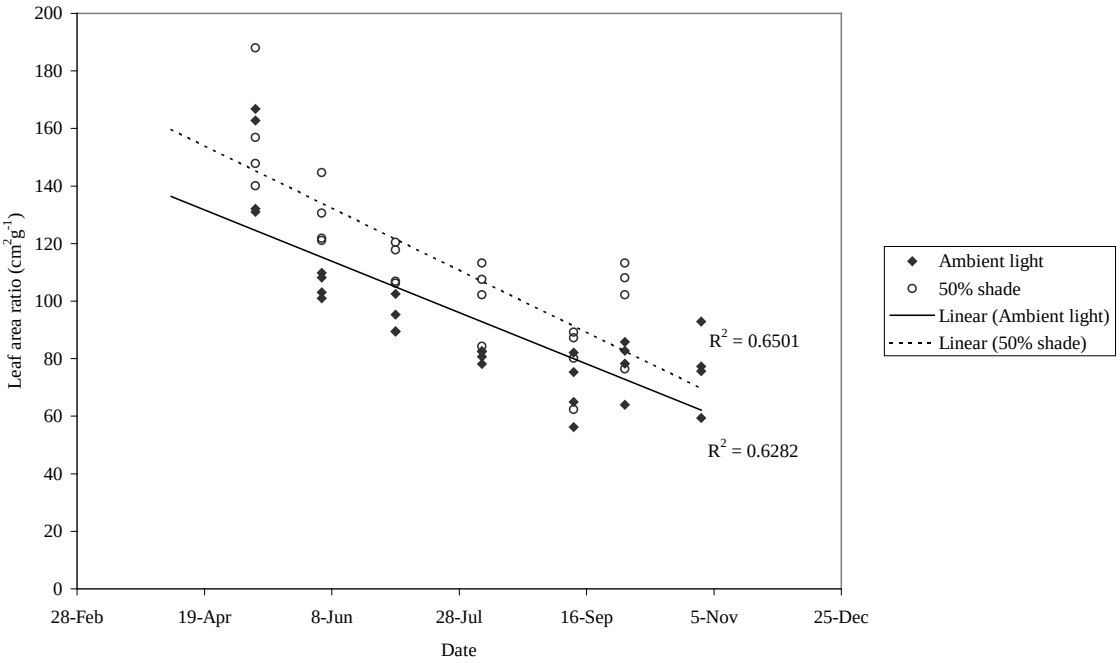


Figure 13. The decline of leaf area ratio (LAR) (cm^2g^{-1}) over the season at four different temperatures, shown for ambient light and 50% shade. LAR was calculated as the ratio of average leaf area per plant (cm^2) to average above ground plant dry weight (g).

Growbag Use, 25% Shade and Pinching Autumn Initiated Flowers - Numerical Links for the Growth Model (6.2)

Runner numbers were greater in bag-grown than in pot-grown plants, indicating that greater vegetative growth was supported by bags. In comparison, pot-grown plants outcropped bag grown plants. The increase in vegetative growth of the bag-grown plants did not, therefore, support larger yields. The commercial practice of pinching flowers in the spring was validated at the end of the season by an improved fruit quality (reduced misshapes), increased total yield and increased early runner production in plants de-blossomed until May (for full details see Annual report 2001 and Interim Report 2001).

Photoperiod Experiment (6.3)

Total fruit fresh weight was greatest in the 10°C/17h treatment, at 678g per plant. The relatively low yields in all treatments in the photoperiod experiment were due to the experimental design, which supported photosynthesis for only 8 hours per day.

Photoperiod had no statistically significant effect on floral initiation throughout the treatments, though plants in short days showed a tendency for a higher rate of flower initiation in the second half of the season. Further, the pattern of flower initiation showed no evidence of 'thermo-dormancy', as there was no significant dip in flower initiation during the season. Crop load, in comparison, showed a trough in production at the beginning of August in the long and short day treatments with a 20°C 'night' compartment temperature.

Conclusions for Experiments 6.1 – 6.3

A capacity for shade tolerance was emphasised by the increase in specific leaf area under 50% shade, indicating a greater source capacity. The full potential of this source capacity was, however, not reflected by yield increases due to the negative effect of shade on berry development. It was hypothesised, however, that application of shade during vegetative growth, prior to berry production, might optimise the source-sink relationship. Photoperiod had no statistically significant effect on floral initiation throughout the treatments and troughs in crop load appeared not to coincide with dips in flower initiation. The rate of flower initiation was high throughout the treatments, which indicates that if decreased production at higher temperatures corresponds to 'thermo-dormancy', it must be a consequence of effects on flower abortion and/or early fruit development. This finding validates the results of experiment 5. Detailed experimentation in year three (experiment 7) was therefore designed to investigate thermo-dormancy with the associated production troughs in more depth, and looked at the possibility of utilising 'Everest' shade tolerance to increase the source capacity during vegetative growth.

Experiment 7) Everbearer Production Model Testing: Test Effects of Cultural/Nutritional Treatments on Everbearer Cropping and Model Predictions (Task 1.9)

Introduction

Experiments 5 and 6 (Tasks 1.2 and 1.7) highlighted the need for further investigation of heat triggered cropping troughs (i.e. 'thermo-dormancy') in 'Everest', and the need for further investigation of the potential of shading to increase the source capacity (leaf area per unit leaf weight) during vegetative growth. A semi-commercial 'pipe & pot' system in a glasshouse compartment provided the base for three experiments conducted in year 3 at The University of Reading.

The first experiment (7.1) established whether shade tolerance (increase in leaf area) could be exploited for increased fruit production. Within the 'pipe & pot' system two differing types of shade netting (25%, 50%) were hung over plants for four or six weeks from 1st April. Fruit production and quality were not affected by the decreased light availability, as shades were removed on 1st May and 14th May respectively.

In experiments 5 and 6 a temperature of 26°C and above was found to result in mid-season cropping troughs. In experiment 7.2 transfer treatments into a 26°C glasshouse compartment established the period of exposure to high temperatures required to induce cropping troughs. Plants were transferred out of the 'pipe & pot' system on the 1st July for 5, 10, 20 and 30 days at 26°C, and were then returned to the 'pipe & pot' system.

The response of flowering and fruiting patterns in 'Everest' to a transfer (30 days) from a 20°C environment into a 26°C environment was studied, with and without a night temperature differential (26°C day/ 13°C night) in a third experiment (7.3). Twelve plants each were transferred into two controlled environment cabinets (Saxcils) for the month of July. This aimed to establish whether 'thermo-dormancy' is triggered purely by a period of high temperature or

whether an interaction with a cool night temperature is required. Crown dissections gave insight into flower initiation in selected temperature treatments.

Materials and Methods

Three experiments were conducted in 2002, based in a 'pipe and pot' system (Field Ltd., Appledore, Kent) in a glasshouse compartment at a set-point temperature of 18^{o}C (actual average 20^{o}C) at the School of Plant Sciences, The University of Reading. These experiments have been reported previously in the Annual Report 2002 and the Interim Report 2003.

Plants of the everbearing strawberry 'Everest' (tray plants supplied by Edward Vinson Ltd., Faversham, Kent) were planted in the second week of March into 2 l pots (ProGro, LBS, Lancashire, England) using strawberry peat bag compost (Westland Horticulture, Dungannon, N. Ireland) and placed in an unheated polytunnel for two weeks to establish before being transferred to the 'pipe and pot' system on 1st April 2002.

An automatic irrigation system was used to supply nutrients to plants via 4l/hour pot drippers (Field Ltd., Appledore, Kent) on average eight times per day between 7 am and 9 pm. Nutrients (N, P, K, Mg, Ca, SO_4 and micronutrients Mn, B, Zn, Cu and MO) were supplied using everbearer feed at a set point electrical conductivity of 1.5 mScm^{-1} and pH set at 5.9.

Six plants were sampled destructively before and after each treatment. Flower initiation was recorded by dissection under the light microscope (Wild Heerbrugg M3 Stereoscope, Switzerland) in the temperature treatments. Further, crown number, leaf number, truss number, flower number and fruit number were measured, as well as leaf areas, appropriate fresh weights and dry weights.

Fruits were harvested from six labelled plants in each of the treatments twice weekly, or as required. Temperature and light level were recorded every 30 seconds and hourly averages were stored by a data logger (DT500, Data Electronics, Welwyn Garden City). Pest control was

carried out as required. In addition biological control of was carried out using *Amblyseius cucumeris* (Novartis Crop Protection Ltd, Cambridge).

A completely randomised design was chosen. Each plant equalled one replicate (six replicates per treatment for destructive sampling), as recommended by the Statistical Advisory Service in the Department of Applied Statistics, The University of Reading. Statistical analyses were conducted using ANOVA procedures from the GENSTAT statistical computer programme (version 6).

Experiment 7.1 Shade Tolerance: Artificially Increase Leaf Area

Plants were grown in a 'pipe and pot' system and 25% and 50% shade was applied to plants for 4 and 6 weeks from the start of the experiment, prior to fruiting:

25% shade for	4 weeks
	6 weeks
50% shade for	4 weeks
	6 weeks

The response of 'Everest' growth, flowering and fruiting patterns to initial periods and intensities of shading was studied. The shade tolerant ability of the plants to increase leaf area was tested for a possible benefit to fruit production.

Experiment 7.2 Thermo-dormancy Triggers: Period of Exposure to High Temperature

Plants were grown in the 'pipe & pot' system at an actual average temperature of 20^{o}C (set-point 18^{o}C). Transfer was to a 26^{o}C glasshouse compartment (July 2002) for four treatment periods (5, 10, 20 and 30 days):

Based in:	*Transferred to:*
Glasshouse compartment 'pipe and pot' system 20°C	26°C GH - 5 days
	26°C GH - 10 days
	26°C GH - 20 days
	26°C GH - 30 days
	Remain in 'pipe and pot' as CONTROL

Following these high temperature treatments the plants were transferred back into the 20°C compartment. The responses of 'Everest' flowering and fruiting patterns were studied to establish the period of high temperature needed to trigger thermo-dormancy.

Experiment 7.3 Thermo-dormancy Triggers: Day/ Night Temperature Differential

The response of 'Everest' flowering and fruiting patterns to a transfer (30 days) from a 20°C environment into a 26°C environment was studied, with and without a night temperature differential. Transfer was to two Saxcil cabinets for one month each in July 2002:

Based in:	*In July 2002 transferred to:*
Glasshouse compartment 'pipe and pot' system 20°C	26°C day/ 26°C night Saxcil cabinet
	26°C day/ 13°C night Saxcil cabinet
	Remain in 'pipe and pot' as CONTROL

A cycling porometer (AP4 – Delta T Devices, Cambridge) gave information on stomatal conductance (cms^{-1}) to loss of water vapour at the end of the transfer period. Following Saxcil treatments the plants were transferred back into the 'pipe and pot' system.

Results and Discussion

Shade Tolerance: Artificially Increase Leaf Area (7.1)

Shading the plants before fruiting in the months of April and May resulted in no significant increase in leaf area or the ratio of leaf area per unit leaf weight (Figure 14). The total period of shading was presumably not long enough to cause these morphological changes. As a result, yield was not significantly affected by pre-fruit shade treatments.

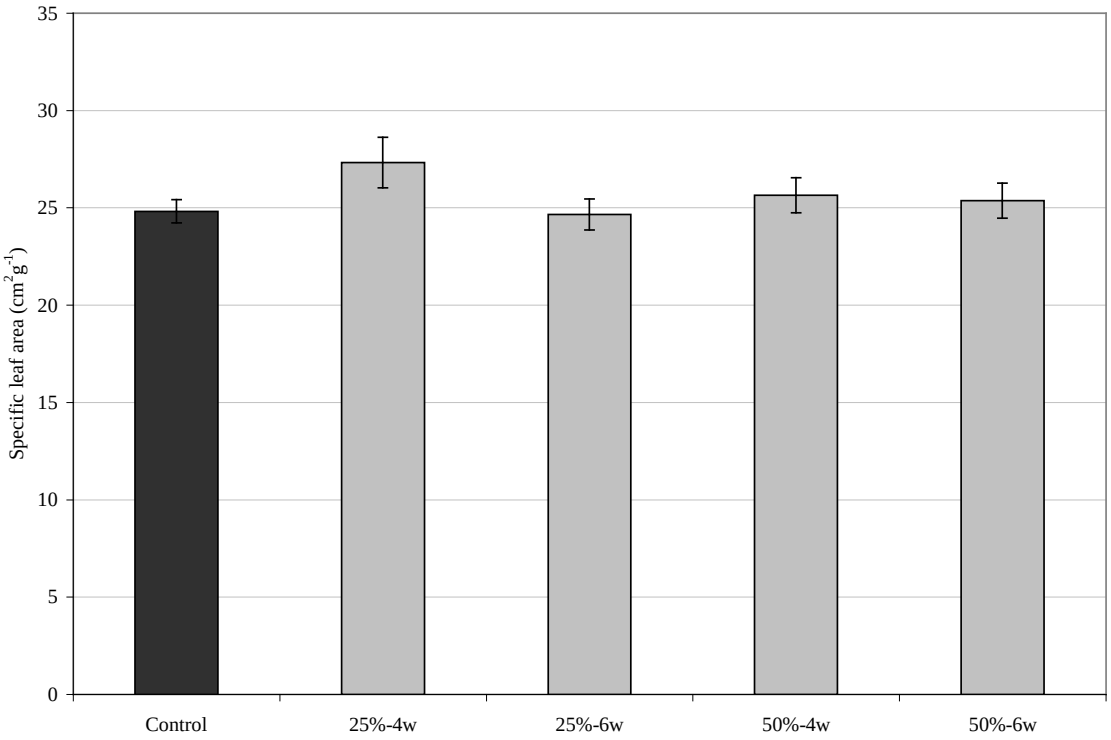


Figure 14. Specific leaf area (SLA). Pre-fruit shading resulted in no significant increase in leaf area per unit leaf weight.

Thermo-dormancy Triggers: Period of Exposure to High Temperature (7.2)

Transferring plants into a 26^{o}C compartment (day/night) for differing periods of time (5, 10, 20 and 30 days) from the 1st July resulted in short cropping peaks early in July, as the high temperature initially accelerated plant development. Even the 5-day transfer treatment, however, showed a dip in cropping in August. The length and severity of thermo-dormancy was dependent on the period of exposure to 26^{o}C (Figure 15). Following thermo-dormancy in August none of

the transfer treatments recovered to produce total yields comparable with the control plants. The 10-day transfer treatment, however, achieved a similar yield to the 5-day transfer treatment, due to increased growth in September. The lowest total yield was recorded in the 30-day (26°C) transfer treatment with 1162g per plant. Transfers of 5, 10, 20 and 30 days therefore reduced total yields by 14, 15, 21 and 32% respectively.

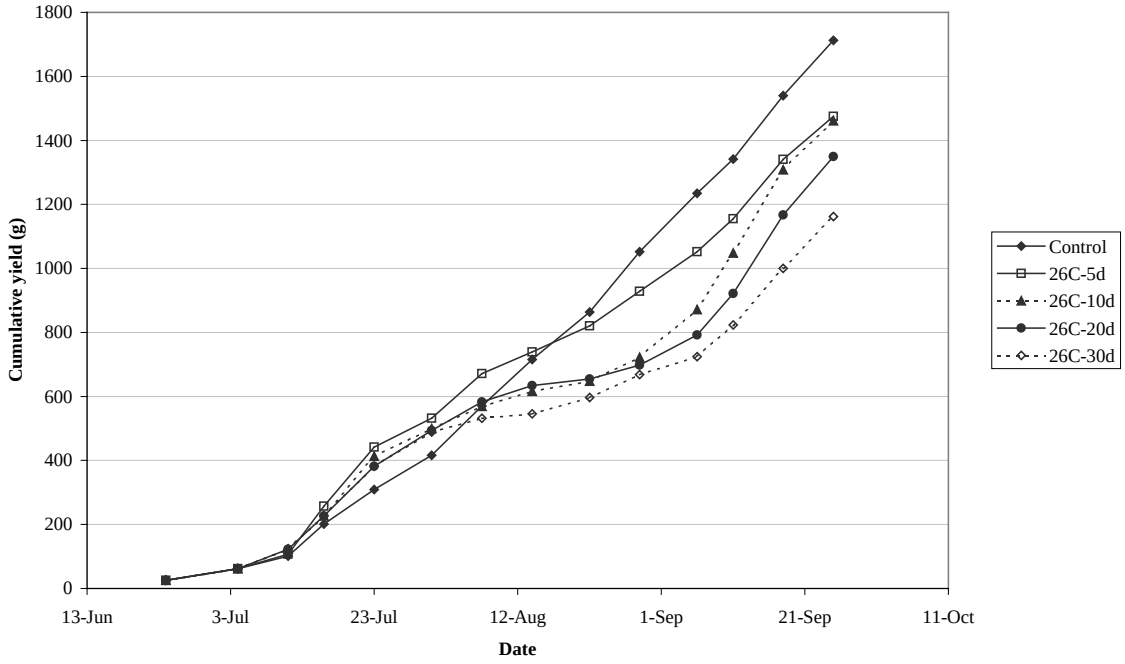


Figure 15. Cumulative yield (g), measured as fruit fresh weight per plant, between April and September 2002. A control treatment and four transfer treatments to a 26°C glasshouse compartment for 5, 10, 20 and 30 days in July are shown.

Thermo-dormancy Triggers: Day/ Night Temperature Differential (7.3)

Controlled environment (Saxcil) cabinets were used to investigate the effect of a day/night temperature differential in relation to cropping troughs, i.e. 'thermo-dormancy'. A massive improvement in the productivity of a crop subjected to high day temperature (26°C) was found if it was also given cool night-temperatures (13°C) (Figure 16). The 26°C day/ 13°C night and the 26°C day/ 26°C night treatments both initially displayed cropping peaks above the control treatment when transferred to high day temperatures in the Saxcil cabinets (1st July- 30th July). Following the return to the 20°C environment ('pipe & pot') the 26°C day/ 26°C night treatment

showed reduced fruit production as expected, giving a thermo-dormancy cropping trough in August. In contrast, those plants that had received cool night temperatures (26°C day/ 13°C night) returned to normal cropping patterns similar to those displayed by the control treatment. The 26°C day /13°C night treatment even outcropped the control treatment with an average 1756g compared to 1713g per plant.

Porometry during the transfer period in July showed transpiration of water vapour from the leaves to be greatest in the control and 26°C/13°C Saxcil treatment, suggesting optimal assimilate partitioning in plants grown at cool night-time temperatures (for full details see Annual report 2002 and Interim Report 2003).

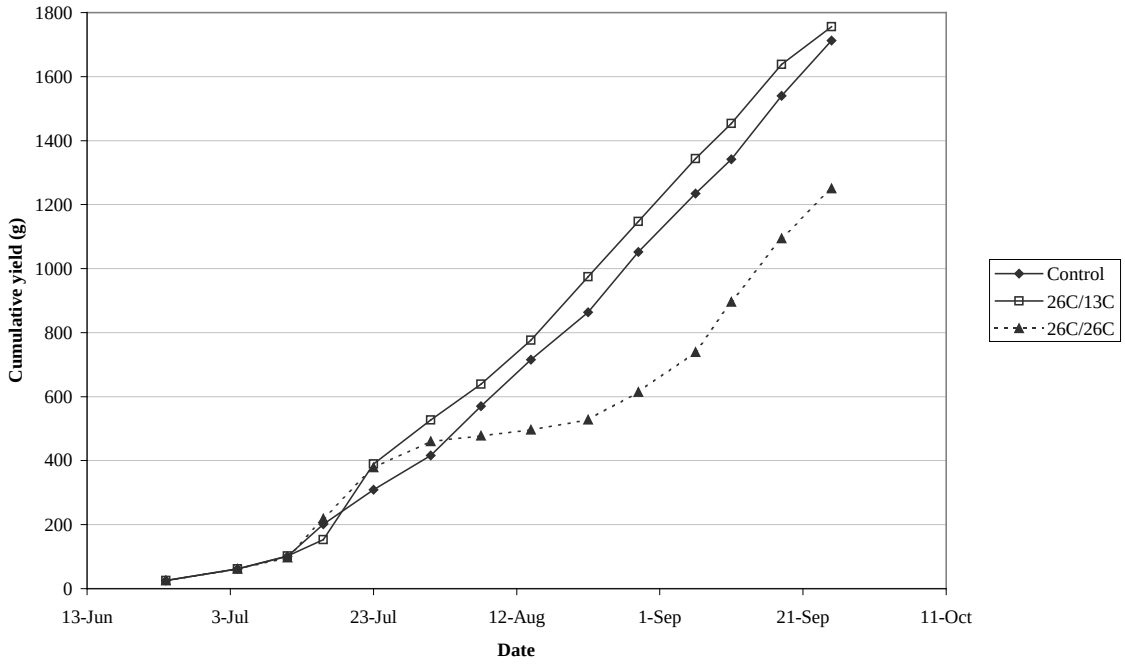


Figure 16. Cumulative yield (g), measured as fruit fresh weight per plant, between April and September 2002. A control treatment and two Saxcil treatments (26°C day/ 13°C night; 26°C day/ 26°C night) in July investigated the effect of a day/ night temperature integral on cropping.

Microscopic flower numbers were increased above those of the control treatment in both Saxcil treatments at the end of the transfer (1st August) by an average of 50 flowers per plant. On the 30th September crown dissections in the control treatment showed a significant increase in microscopic flower numbers compared to the 1st August, with 82 flowers rather than 60 flowers

per plant. The Saxcil treatments (26°C/13°C; 26°C/26°C), however, reduced microscopic flower numbers over this two-month period by 31% and 37% to 73 and 45 flowers per plant respectively on the 30th September. The higher microscopic flower numbers in the Saxcil treatments on the 1st August were not followed by higher 'grown out' macroscopic flower numbers by the end of the experiment (30th September). A possible explanation is that the burst of high temperature in the Saxcil treatments in July triggered an initial increase in flower initiation, which was followed by an increased rate of flower abortion compared to the control treatment, resulting in a similar final macroscopic flower number in the 26°C/13°C treatment and a reduction of final macroscopic flower number in the 26°C/26°C treatment. This observation is consistent with the yield data of this experiment, as the control and the 26°C day /13°C night treatment produced similar yields, in contrast to the significantly reduced yield in the 26°C/26°C treatment.

In conclusion treatments applied in this experiment (Task 1.9) helped to address specific issues that arose from experiments 5 and 6 (Tasks 1.2 and 1.7). Transfers into a 26°C environment for as little as 5 days in July were capable of triggering 'thermo-dormancy' by reducing flower and fruit production in the month of August. Total fruit fresh weight over the season was greatest in the 26°C/13°C growth cabinet treatment. A cool night temperature therefore resulted in highly productive plants, which did not show signs of thermo-dormancy, whereas those at a 26°C day/night temperature did. Physiological mechanisms happening before, during and after 'thermo-dormancy' were investigated in the final year, as well as the suggested central role of night temperature (experiment 8).

Experiment 8) Evaluation of Experimental Findings at Reading: Model Validation and Monitoring (Task 1.11)

Introduction

Experiment 8 (Task 1.11) evaluated the system established over the first three years for 'Everest' under controlled conditions at The University of Reading. Originally, water stress treatments for optimum fruit quality were to be monitored for their effects on continuity of flowering and

fruiting, particularly where interactions with high temperatures occurred. These water stress treatments, however, became redundant due to findings in experiments 3 and 4.

Instead, detailed Saxcil transfers from a semi-commercial 'pipe & pot' system aimed to validate and extend the analysis of temperature effects on 'Everest' observed in the previous years. In experiment 8.1 particular attention was paid to temperature induced cropping troughs (thermo-dormancy) and the role of night-time temperature. Three treatments were repeated from year 3, with the purpose of system and model validation. A new treatment, in which plants were transferred into 26°C/13°C for 5 days, studied cropping patterns caused by a short period of transfer (plants transferred into a 26°C/26°C environment for 5 days showed signs of thermo-dormancy in experiment 7). Two further treatments investigated thermal-time aspects, by subjecting plants to the same thermal-time, by different day-night regimes. Here plants were subjected to a 13°C/26°C day and night temperature, or the 24 hour average of these, 22°C.

In a second experiment (8.2) plant growth and cropping were compared between the standard peated compost and a bark/loam mix (as recommended by ADAS work from years 1 and 2 – Objective 3). This aimed to test this substrate as a peat free alternative, and to enable comparison across the scientific partners of the LINK project.

Materials and Methods

Two experiments in 2003 (8.1 and 8.2) were based in a 'pipe and pot' system (Field Ltd., Appledore, Kent) in a glasshouse compartment at a set-point temperature of 18°C (actual average 21°C) at the School of Plant Sciences, The University of Reading. These experiments have been reported previously in the Annual Report 2003.

Plants of the everbearing strawberry 'Everest' (tray plants supplied by Edward Vinson Ltd., Faversham, Kent) were planted in the second week of March into 2 l pots using strawberry peat bag compost and peat free: bark loam mix (90%/10%) (Westland Horticulture, Dungannon, N. Ireland) and placed in an unheated polytunnel for two weeks to establish, before being transferred to the 'pipe and pot' system on 1st April 2003.

An automatic irrigation system was used to supply nutrients to plants via 4l/hour pot drippers (Field Ltd., Appledore, Kent) on average eight times per day between 7 am and 9 pm. Nutrients (N, P, K, Mg, Ca, SO_4 and micronutrients Mn, B, Zn, Cu and MO) were supplied using everbearer feed at a set point electrical conductivity of 1.5 $mScm^{-1}$ and pH set at 5.9.

Six plants in each of the treatments were sampled destructively at the end of July and at the end of the experiment. Flower initiation was recorded by dissection under the light microscope (Wild Heerbrugg M3 Stereoscope, Switzerland) in the temperature treatments. Further, crown number, leaf number, truss number, flower number and fruit number were measured, as well as leaf areas, appropriate fresh weights and dry weights.

Fruits were harvested from six labelled plants in each of the treatments twice weekly. Temperature and light level were recorded every 30 seconds and hourly averages were stored by a data logger (DT500, Data Electronics, Welwyn Garden City). Pest control was carried out as required. In addition biological control was carried out using *Amblyseius cucumeris* (Novartis Crop Protection Ltd, Cambridge).

A completely randomised design was applied. Each plant equalled one replicate (six replicates per treatment for destructive sampling), as recommended by the Statistical Advisory Service in the Department of Applied Statistics, The University of Reading. Statistical analyses were conducted using ANOVA procedures from the GENSTAT statistical computer programme (version 6).

Experiment 8.1 Effects of Varying Temperature Regimes on Thermo-dormancy

'Everest' plants were transferred from the 'pipe and pot' system (21^{o}C) into six Saxcil cabinets on 1st July 2003. Following Saxcil treatments, plants were transferred back into the 'pipe and pot' system.

Based in pipe & pot:	Transferred into:
21°C glasshouse compartment	Remains in 21°C GH compartment as Control
	26°C day/ 26°C night Saxcil cabinet – 5 days
	26°C day/ 13°C night Saxcil cabinet – 5 days
	26°C day/ 26°C night Saxcil cabinet – 30 days
	26°C day/ 13°C night Saxcil cabinet – 30 days
	13°C day/ 26°C night Saxcil cabinet – 30 days
	22°C day/ 22°C night Saxcil cabinet – 30 days

Experiment 8.2 Peat-free Growth Substrate

Growth, flowering and fruiting patterns of 'Everest' in peat-free substrate (bark/loam mix) within the 'pipe and pot' system were studied and compared to the standard peat based compost:

Peat based compost	vs.	Bark and loam mix (90%/10%)

This aimed to test whether a similar productivity occurred in either substrate, parallel to a specifically conducted substrate experiment by ADAS (Objective 3).

Results and Discussion

The increased glasshouse air temperatures in 2003 resulted in relatively lower overall yields than in 2002. The control treatment grown in the 'pipe and pot' system yielded an average 1713g per plant in 2002 compared to 1180g in 2003, a reduction of 533g between years.

Temperature Experiment 8.1

Transfers to six Saxcil cabinets allowed the application of specific day and night temperatures for two durations in July. The findings from experiments 5, 6 and 7, on the effect of duration and

application of high temperatures on the continuity of flowering and fruiting were validated, by describing similar crop growth patterns.

Short bursts (5 days) of a high day-time temperature (26°C) were shown to be responsible for bringing the July cropping peak forward by at least one week (Figure 17). A reduction in night-time temperature was again shown to be beneficial for reducing heat-induced cropping troughs during a potentially productive phase of growth in August (Figure 17). The average yield (total fruit fresh weight, g) picked on the 13th August was 126 g per plant in the Control and 103 g in the 26°C/13°C-5day treatment, when a 26 night-temperature caused yield to drop by approximately half, to 56 g per plant in the 26°C/26°C-5day treatment.

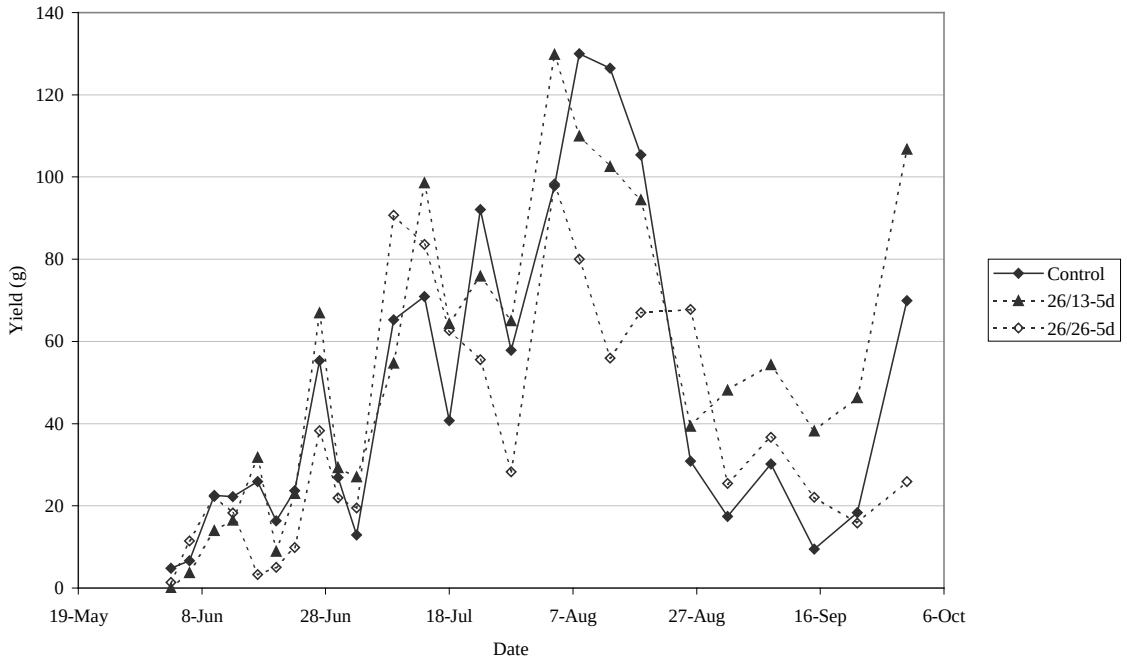


Figure 17. Fruit yields at point of harvest (g) per plant between April and September 2003. A control treatment and two Saxcil treatments (26°C day/ 13°C night for 5 days and 26°C day/ 26°C night for 5 days) in July investigated the effects of day/ night temperature integrals on cropping.

Switching to 26°C during darkness negatively affected the cropping behaviour of the 13°C/26°C-30day treatment (Figure 18), possibly due to increased rates of dark-respiration. Total yield of the 13°C/26°C-30day treatment was reduced by 30% to 828g per plant, compared to the Control. A cropping dip in August was found in this Saxcil treatment, supporting the hypothesis that

night-time temperature is the main trigger for thermo-dormancy, rather than a high average daily temperature.

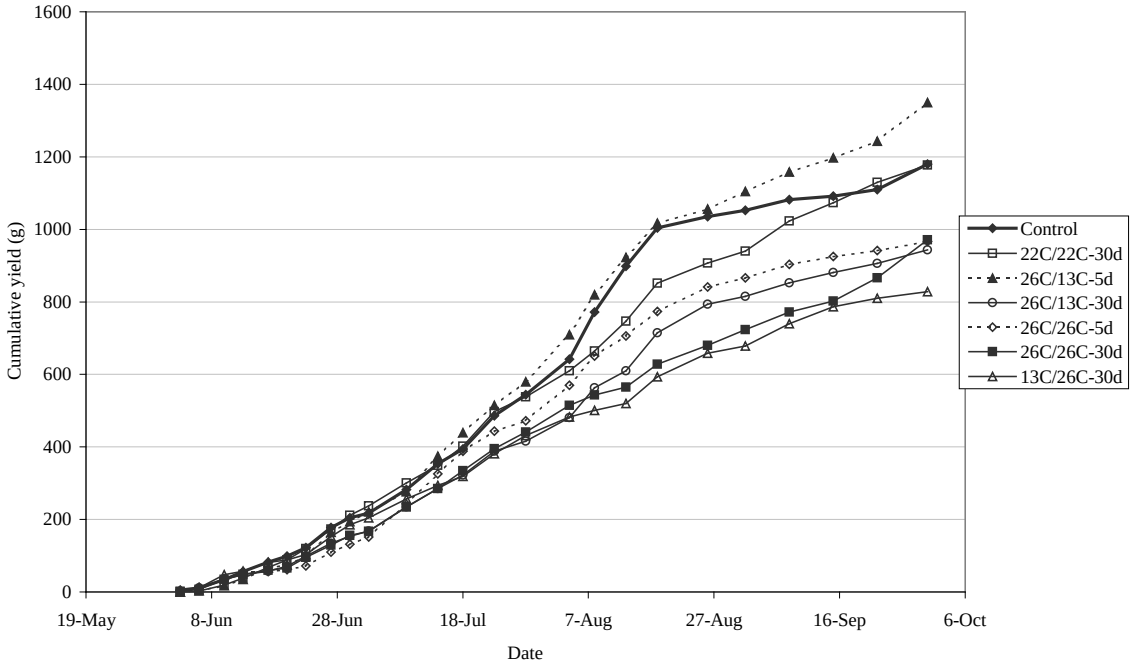


Figure 18. Cumulative yield (g), measured as fruit fresh weight per plant, between April and September 2003. A control treatment and six Saxcil treatments (22°C day/ 22°C night for 30 days (acting as a further control); 26°C day/ 13°C night for 5 and 30 days; 26°C day/ 26°C night for 5 and 30 days; 13°C day/ 26°C night for 30 days) in July investigated the effects of day/ night temperature integrals on cropping.

The number of flowers initiated between the end of the various transfer treatments and the end of September varied significantly ($P<0.01$) (Figure 19). Variation between plants was large, which is shown by the large standard error values. Macroscopic flower number was also affected by temperature to show highly significant differences on the 31st of July ($P<0.001$) (details given in the Annual Report 2003). Temperature appeared to affect the development or abortion of already initiated flowers more than the initiation process itself. The initiation results differ from those in experiment 7, where no increase was found when a 13°C night-temperature was applied; initiated flower numbers here were reduced by 50%. A likely explanation for this discrepancy is the correlation between crown number and number of initiated flowers, indicating a relationship between crown numbers produced by a plant and the subsequently available flower initiation sites. The crown numbers in the 26°C day/ 13°C night treatments were lower than in the control treatment.

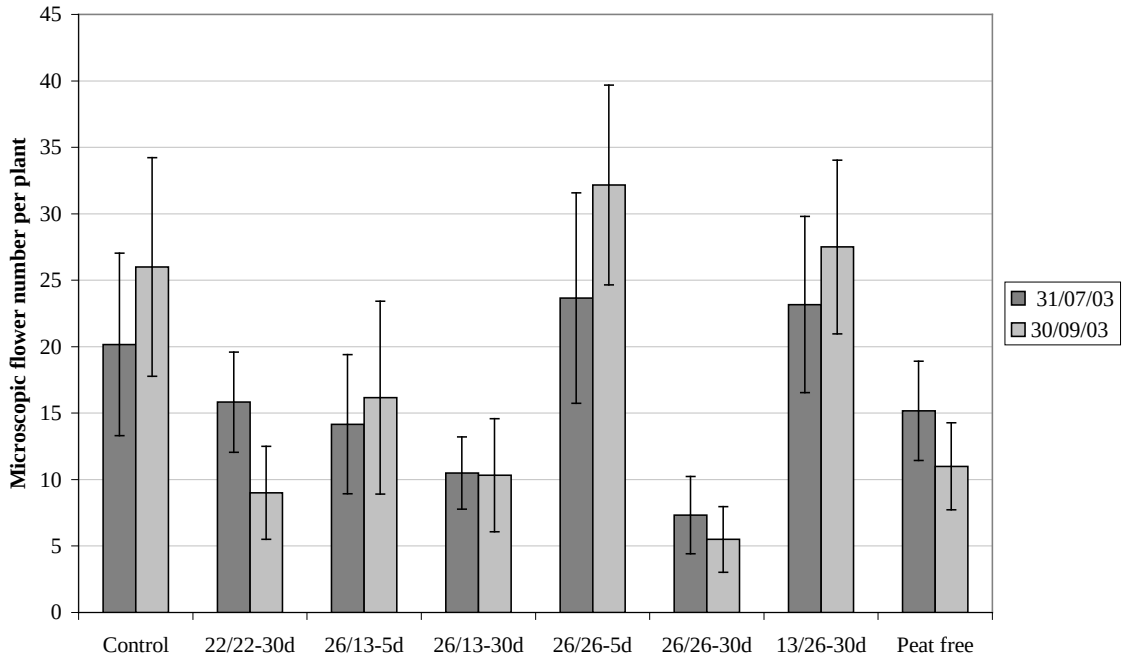


Figure 19. Initiated flower numbers observed via dissection under the microscope. Shown per plant for two dates in the control treatment, the six Saxcil transfers and the peat-free substrate treatment. Vertical bars show ± standard errors.

Substrate Experiment

The peat-free, bark/loam mix gave low production rates from August, resulting in low total yields per plant of 907g (Figure 20). It also significantly reduced final crown number, crown fresh weight and leaf number compared to the control treatment. It should be noted that the two substrates supported very similar crops up to the 8th August, with the peat free compost yielding only marginally less. Thereafter, however, yield differences became marked. This may have been due to the amount and type of fertigation applied, as this was based on that required for the peated compost. Whether a change in the air filled porosity of the bark/loam mix resulted in poorer root development late in the season remains unknown.

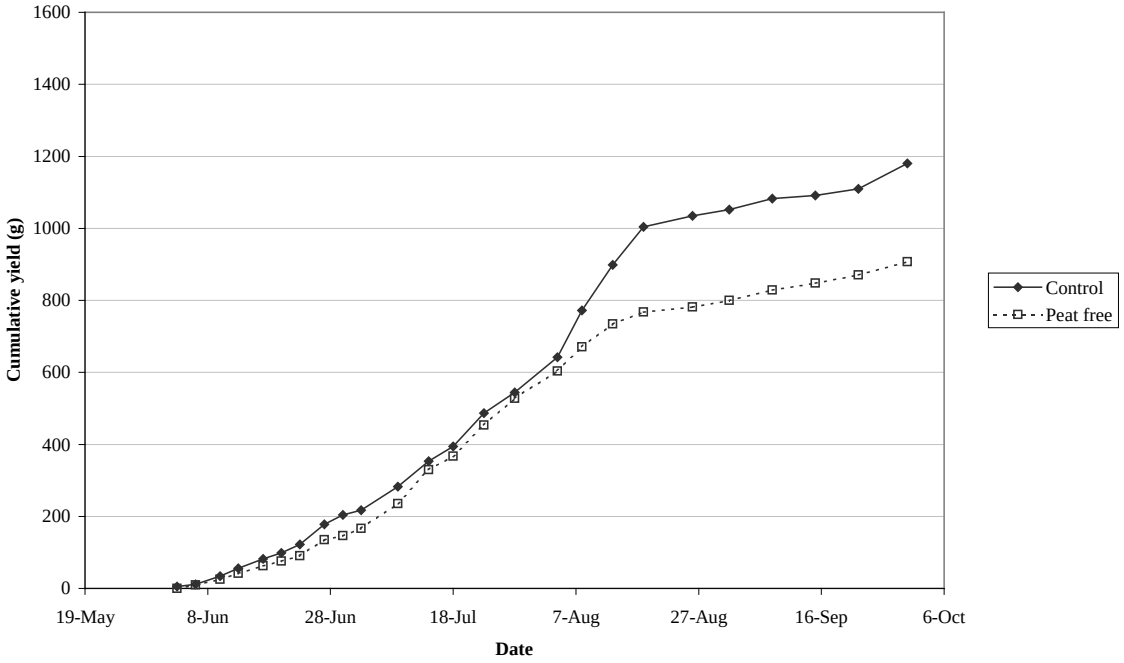


Figure 20. Cumulative yield (g), measured as fruit fresh weight per plant, between April and September 2003. A control treatment is compared to a substrate treatment in peat free compost (Bark/loam mix 90%/10%).

Conclusions From Objective 1

Flavour Analysis in Strawberry and Responses to its Water Environment

It is clear from the flavour analysis that APCI is a useful technique for rapid determination of fruit volatiles. The results from the flavour analysis indicate that there is a large variation in flavour compounds between harvests. Later results from this LINK project (Watson *et al.* 2003) showed that there is also a large variation between fruits from a single harvest. The aim of the grower should be to minimise these differences. Manipulation of volatiles is not currently possible but techniques to maximise light interception and hence the availability of assimilates are important (see Objective 2).

It appears that water stress is not suitable for fruit flavour manipulation in strawberry. There was very little indication of flavour improvement using water stress and stress led to yield reductions.

Electronic Systems for Controlled Water Stress

It was shown that, in principle, a computer-controlled weighing system for transpiration monitoring and irrigation control could be used in commercial production if required by the industry. It is suggested that such a system could be used to monitor water use in a few typical bags within a large production area, and then the electronic output would be used to control the irrigation to all the bags within the production unit. This type of system may become of value to the industry when there is a need or desire to decrease bag run-off, to limit ground water pollution and use of water. In comparison, when interpreting measurements with instrumentation for direct measurement of soil moisture content it was found that uncertainties caused by moisture gradients indicate caution is required. It was shown that the usefulness of the TDR and the Theta probe were limited in commercial systems based on media grow-bags.

Shade Adaptation

'Everest' showed a clear capacity for shade adaptation. Crown numbers were significantly reduced by low light conditions, but LARs were increased to values higher than in plants grown at ambient light. This indicated an increase in the photosynthetic capacity of the leaf, a response typical of shade adaptation (Gulias *et al*., 2003; Wright and Sandrang, 1995). This response was, however, insufficient to compensate for loss in yield. In Junebearers, Fletcher *et al.* (2002) showed that 'Elsanta' was capable of some compensaton for reduced light, as a 63% reduction in light caused a 52% reduction in yield. Limited shading of 'Hapil' (25%) caused little change in plant morphology, while heavier shade led to increases in leaf area per unit ground area caused by an increase in SLA (Wright and Sandrang, 1995). The general picture that emerges is of *Fragaria* as a shade tolerant genus, but with reductions in fruit yield nevertheless being a seemingly inevitable consequence of reduced light availability. In 'Everest', plants receiving pre-fruit shading (Experiment 7.1) did not suffer yield reduction; their source capacity, however, was also not improved, as leaf area ratios were not increased. A commercial exploitation of pre-fruit shading for increasing yield capacity in 'Everest' was therefore found not to be viable.

The potentially detrimental effect on yield of reduced light levels is a result of practical relevance, emphasised by a significant reduction in crown number under shade found in experiments 5 and 6. This means that crown number is the limiting factor for yield potential in 'Everest', a significant finding in view of the increase in protected cropping (glasshouses, polytunnels) of strawberries, which can lead to reduced light levels compared to those experienced by outdoor crops.

High Temperature Yield Compensation and Assimilate Partitioning

The capacity for yield compensation at high temperatures was similarly limited, as the increase in fruit number with increased temperature did not prevent a reduction in yield. In 'Everest' grown at high temperatures, the fruit-filling phase was shortened, reducing total fruit weights, as found in Junebearers (Le Mière *et al*., 1998). 'Everest' compensated for this by producing more fruit more quickly. This compensation led to higher overall fruit yield as temperature increased to

about 23°C; above this temperature the size of fruit decreased and yield started to fall, even though fruit number continued to increase up to 27°C. Our results are consistent with those of Kumakura and Shishido (1995), who found temperatures between 20 and 25°C to be best for flowering in four everbearing strawberry cultivars ('Everberry', 'Enrai', 'Summerberry' and 'Hecker'). This is different to the trend found in Junebearers, where a temperature optimum of 18°C was found for fruit dry matter production by Heide (1977). Le Mière *et al.* (1998) found temperature to be negatively correlated to yield, berry number and average berry weight, with highest yields in 'Elsanta' at 15°C.

Harvest index measurements showed that the distribution of assimilates between vegetative and reproductive growth, i.e. fruiting, was temperature dependent. An increase in developmental rate at warmer temperatures coincided with a reduction in source capacity, with 'Everest' plants producing less green matter and smaller leaf areas. This reduced the availability of assimilates that could be partitioned towards fruit at 27°C. The harvest index, however, was similar for all temperature treatments above 21°C, with an average assimilate partitioning of 64% to fruit. This is in agreement with findings of Camacaro *et al.* (2002) who recorded a harvest index of 59% in 'Everest' grown outdoors. At 15°C, in experiment 6.1, the harvest index was 35%; significantly less assimilate was therefore partitioned towards fruit. This indicates a dominance of vegetative growth at this cooler temperature, which is emphasised under low light conditions (harvest index of 18%).

The everbearing strawberry initiates flowers throughout the season, at the same time as cropping. The Junebearing strawberry, in contrast, initiates flowers during the preceding autumn; cooler (spring) temperatures typically offer a prolonged period for these flowers to develop into fruit and for the fruit to fill. Junebearers might therefore be expected to have an advantage over everbearers, in terms of assimilate partitioning potential during the fruit production phase, even though overall yield potential is more limited than in everbearers. However, our findings show that the everbearer 'Everest' has a strikingly higher temperature optimum for yield (23°C) than the Junebearer 'Elsanta' (15°C). This may be an adaptation associated with fruiting under the higher temperatures of summer, and it has important implications for optimised crop production of 'Everest'.

Photoperiod and Temperature Effects on Flower Initiation

The classification of everbearing strawberry cultivars is based on photoperiodic responses. Most common divisions have been made between European long-day 'everbearing' varieties, which initiate flowers primarily when days exceed 12h, and American day-neutrals, which are daylength insensitive. As found by Nicoll and Galletta (1987), however, continuums in growth habit and flowering behaviour make rigid classifications between day-neutrals and long-day 'everbearers' difficult. Even so, a practical observation is that everbearing varieties typically produce fruit in flushes continuously from July until temperatures drop too low in October/November (Taylor and Simpson, 2001).

Experiments 5 and 6 showed that in 'Everest' the initiation of floral meristems was not significantly affected by photoperiod. Temperature repeatedly appeared to affect the development or abortion of already initiated flowers more than the initiation process itself. This is consistent with experiments looking at temperature (20, 25, 30^{o}C) and photoperiod (4, 8, 12, 16h) in four everbearing cultivars ('Everberry', 'Enrai', 'Summerberry' and 'Hecker'), where flower bud differentiation was found under all growing conditions, but where a high frequency of flower buds aborted before anthesis in the 30^{o}C treatment (Kumakura and Shishido, 1995). In contrast, Oda and Yanagi (1993) found that flower initiation rates in 'Summer-berry' were 100% at mean temperatures less than 23^{o}C but fell to 0% at mean temperatures above 26^{o}C.

Further work in Japan indicates interactions between photoperiod and temperature, e.g. the everbearer 'Summer-berry' was found to be a quantitative long-day plant at the lower day/night temperatures of 20/15 and 25/20^{o}C, but a qualitative long-day plant at 30/25^{o}C. This means that inflorescences developed in the two cooler temperature environments, with a preference for a 24h rather than an 8h day. At 30/25^{o}C however, the development of inflorescences ceased under a short day of 8h light (Nishiyama *et al*., 1999). Taimatsu and co-workers (1991) found that flower buds were initiated in 'Summer-berry' at 15, 20 and 25^{o}C with 8 or 16h days, but at 25^{o}C with 8h days flower buds were either not produced, or developed non-uniformly. These results are consistent with a general picture that emerges for everbearer flowering of daylength insensitivity at cooler temperatures, a preference for long days at intermediate cropping temperatures, and a

requirement for long days at high average temperatures. As Taylor (2002) points out, it is not always obvious whether negative effects of environment on cropping are due to changes in flower initiation, or to abortion of flowers pre- or post-anthesis. We found no evidence, however, of photoperiod effects on flower initiation in 'Everest', although there was an indication that increased temperature promoted initiation, particularly when given for short time periods.

Thermo-dormancy

In this work, a reduction in total seasonal flower initiation was found in 'Everest' exposed to temperatures of 26^{o}C and above. The number of microscopic flowers was, however, not as strongly affected as the rate of flower bud abortion. A reduced number of grown-out flowers in heat stressed plants were found to result in lower yields, which were recorded as dips in fruit production in August. Consistent with this, 'thermo-dormancy' describes mid-season cropping troughs that are caused by warm temperatures (Angenendt and Battey, 2003).

The severity, duration and pattern of temperatures required to trigger a cropping trough in 'Everest' were defined in experiments 7 and 8. Experiments 5 and 6 identified temperatures of 26^{o}C and above to reduce cropping in 'Everest'. Transfer from a 20^{o}C into a 26^{o}C environment was therefore chosen for a definition of the period of heat exposure required for triggering thermo-dormancy. Periods as short as five days were sufficient to significantly reduce the August crop-load, but longer periods of 10, 20 and 30 days linearly further reduced yields. Reduction of the night-time temperature by half, to 13^{o}C, was found beneficial to the cropping pattern by preventing or significantly reducing thermo-dormancy. This beneficial effect extended to an improvement of total yield per plant above the control treatment in the 26^{o}C/13^{o}C-30day and 5day growth cabinet treatments in experiments 7 and 8 respectively. In experiment 7 the number of flowers initiated at the end of the transfer treatment was significantly increased in the 26^{o}C/13^{o}C-30day treatment. Within a commercial production system the important role of average temperature on crop production was highlighted in a study in Japan, when high August temperatures giving average ground surface temperatures of 25-26^{o}C, resulted in failure of the everbearer 'Kaho' to produce flower buds (Taimatsu *et al.*, 1991). Similarly, off-season production of 'Summer-berry' was found to be improved at higher altitudes in the Korean

republic. Lower average temperatures at the higher altitudes resulted in greater numbers of flowers per plant (SangWook *et al.*, 1996). Manakasem and Goodwin (2001) found that daylength did not limit floral initiation in three day-neutral cultivars; however, poor floral and fruit development occurred outside a temperature range of 18/13^{o}C to 21/16^{o}C.

A query that arose from experiment 7 was whether it was specifically the beneficial effect of a cooler night-time temperature that aided cropping, or whether it was purely an effect of average temperature. One treatment in experiment 8 therefore looked at switching to 26^{o}C during darkness and 13^{o}C during the day. This temperature regime (13^{o}C/26^{o}C-30day) was found to negatively affect the cropping behaviour of the treatment during and after the transfer period. A possible explanation could be that a cool day-time temperature had a tendency to reduce levels of photosynthesis. Levels of dark respiration may have been increased with high night-time temperatures, which would have resulted in a loss of energy from stored assimilates. Furthermore, the 13^{o}C/26^{o}C-30day treatment displayed a cropping dip in August, which suggests that high night-time temperature may be the main trigger for thermo-dormancy. A suggestion of a significant influence of cool night temperatures comes from the work of Yanagi and Oda (1989, 1990 and 1993). They found flower initiation rates in everbearing cv. Summer-berry to be 100% at mean temperatures less than 23^{o}C, but these fell to 0% at mean temperatures above 26^{o}C. Where everbearers 'Rabunda' and 'Ostara' had been given a day-night temperature differential of 30/10^{o}C, in comparison, these workers found that plants continued flowering.

Conclusions on Temperature, Light and Water Management

In conclusion, commercial growing systems may not be able to completely prevent 'thermo-dormancy', but improved materials (e.g. heat-reducing polythenes) and new techniques in crop husbandry could decrease its severity. A temperature optimum of 23^{o}C was found for cropping in 'Everest'; the role of night temperature is crucial. In addition, the importance of optimising light intensity was emphasised by the fruit flavour experiments and is further discussed in Objective 2. Next to optimal fruit quality, maximum fruit quantity was shown to require high light intensity, as shade significantly reduced crown number and thus limited yield. Further work is recommended to focus on the improvement of the structures and materials used in protected

cropping, with particular emphasis on the use of spectral filters for temperature and light quantity and quality management. For water management, a computer-controlled weighing system could be used, in principle, to control the irrigation in commercial production to potentially decrease bag run-off, to limit ground water pollution and use of water.

Everbearer Production Model

Introduction

The soft fruit industry, like other sectors of the food production industry, is highly dependent on the weather. This is uncontrollable, yet the grower is required to supply a consistent supply of high quality produce. Short- to medium term weather forecasts enable a degree of yield prediction, vital for the successful marketing of strawberries. The influence of environmental conditions on crop growth and yield in the everbearer 'Everest' were demonstrated in Experiments 5 to 8 of Objective 1.

The introduction of everbearing cultivars has extended strawberry cropping seasons in the UK; yields, however, have been found to vary between years according to environmental conditions. Temperature, in particular, has been found to influence everbearer cropping, where peaks of high temperature can lead to cropping troughs (i.e. thermo-dormancy) (Angenendt and Battey, 2003; SangWook *et al*., 1996; Taimatsu *et al*., 1991; Yanagi and Oda, 1989, 1990 and 1993). In order to describe and predict the responses of everbearers to their environment, a predictive cropping model has been developed and progress towards this objective is described here.

The complex patterns of assimilate partitioning in everbearers, in which fruiting and vegetative growth coincide over the season (Camacaro *et al*., 2002), makes this task more difficult in 'Everest' compared to the Junebearer 'Elsanta'. Similar modelling approaches to those found in a simple mechanistic peanut model (Hammer *et al*., 1995) and a field bean model (Angenendt, 2001) have been used for the establishment of temperature/yield relationships in this model.

The everbearer 'Everest' model developed here simulates yield patterns predicted over a 14-day period, based on actual and forecast temperature data. Ongoing work is focusing on model

improvement to include light as a driving variable next to temperature, and to include daily temperature differentials for the prediction of thermo-dormancy. Further validation against commercial cropping data will be required to enable the production of modelling software, and this could form part of a new project.

Methods and Model Development

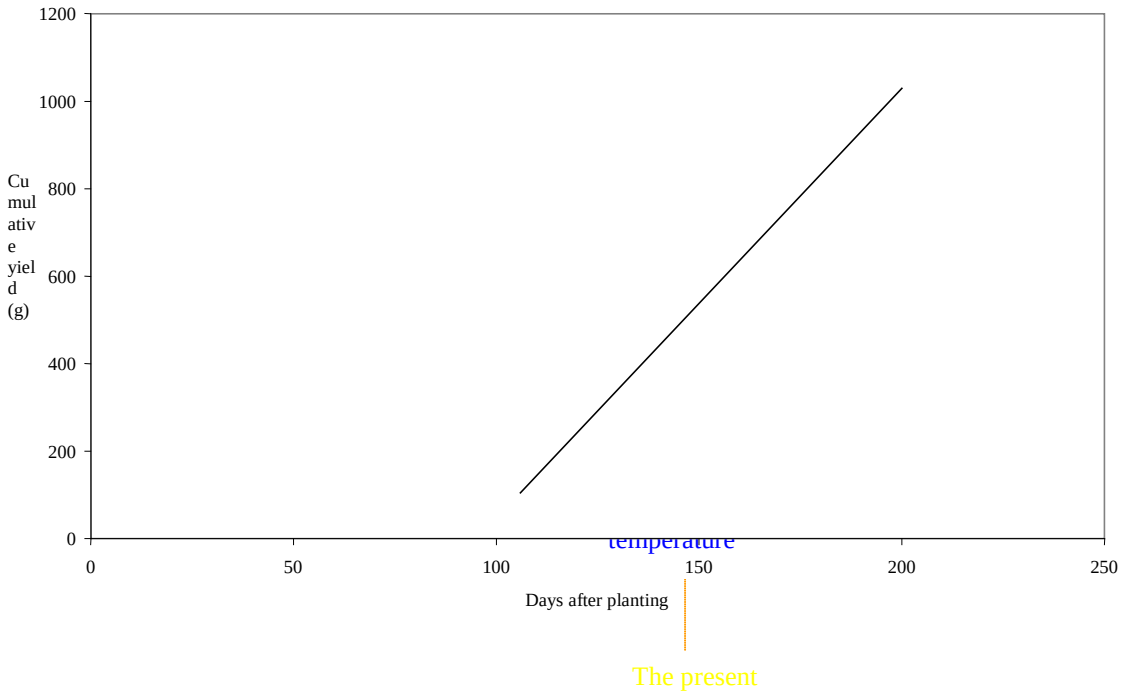
Experiments 5 to 8 at The Univeristy of Reading provided a detailed description of environmental effects on everbearer production. Cumulative yields of 2001 were used for 'Everest' model development. Four temperatures (15^{o}C, 21^{o}C, 23^{o}C and 27^{o}C) and two light integrals (ambient light and 50% shade) supplied environmental effects to establish simple relationships for the model. Cumulative yields were plotted against days after planting (DAP). Daily time-steps were used for the model.

The fit of the model was then tested against the measured cumulative yield data of 2001. The suitability of the cumulative yield data of 2000 was also tried and tested, but found unsatisfactory due to reduced growth caused by low air filled porosity of the peat.

Cumulative yield data of 2002 and 2003 were thereafter used to validate and monitor the model as two datasets independent of model development.

The simulations were based on moving average temperature and moving average growth rate. Simulations were run in a spreadsheet software (Excel) and statistical analyses conducted in Excel and GENSTAT statistical computer programme (version 6).

The timescales for moving average temperature and moving average growth rate are shown in the following diagram, where t_0 specifies the given day; t_{-14} fourteen days previous; t_7 seven days and t_{14} fourteen days in advance:



Of particular interest for model development and prediction was the linear growth phase of cumulative yield between July and September. The focus on this phase of growth enabled the fitting of linear regressions. Figure 21 shows good regression fits for 21, 23 and 27^{o}C with R^2 values of 99, 98 and 97% respectively. The cumulative yield data of the 15^{o}C treatment described a less linear pattern, reflected in a reduced R^2 value of 83%. Cumulative yields of plants at 50% shade also enabled linear regressions to be fitted (Figure 22). The high R^2 values in all temperature treatments show that between 93 and 96% of the variation around the line is described by the regressions. The use of linear regressions gives an approximation of the increase in cumulative yield, however, in that irrespective of the R^2 values discussed, recorded cumulative yields did sometimes not increase linearly. For example, a decline in growth rate was found around 160 DAP in most temperature treatments. Sensitivity towards this dip in production was therefore not provided by the current analysis.

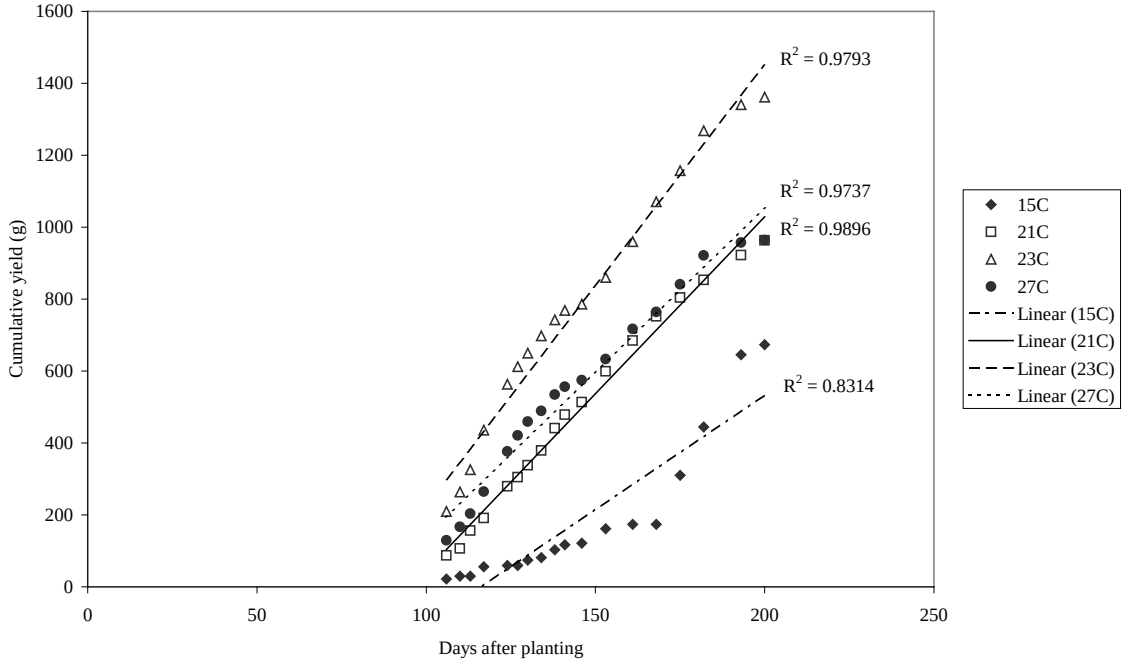


Figure 21. Cumulative yield (g), measured as fruit fresh weight per plant, between July and September 2001 (105 – 200 DAP) at four different temperatures at ambient light. R^2 values show the fit of the linear regression lines described by the equations:
y = 6.3897x - 743.97 (15°C); y = 9.8388x - 939.04 (21°C); y = 12.251x – 1000 (23°C); y = 9.1785x - 780.8 (27°C).

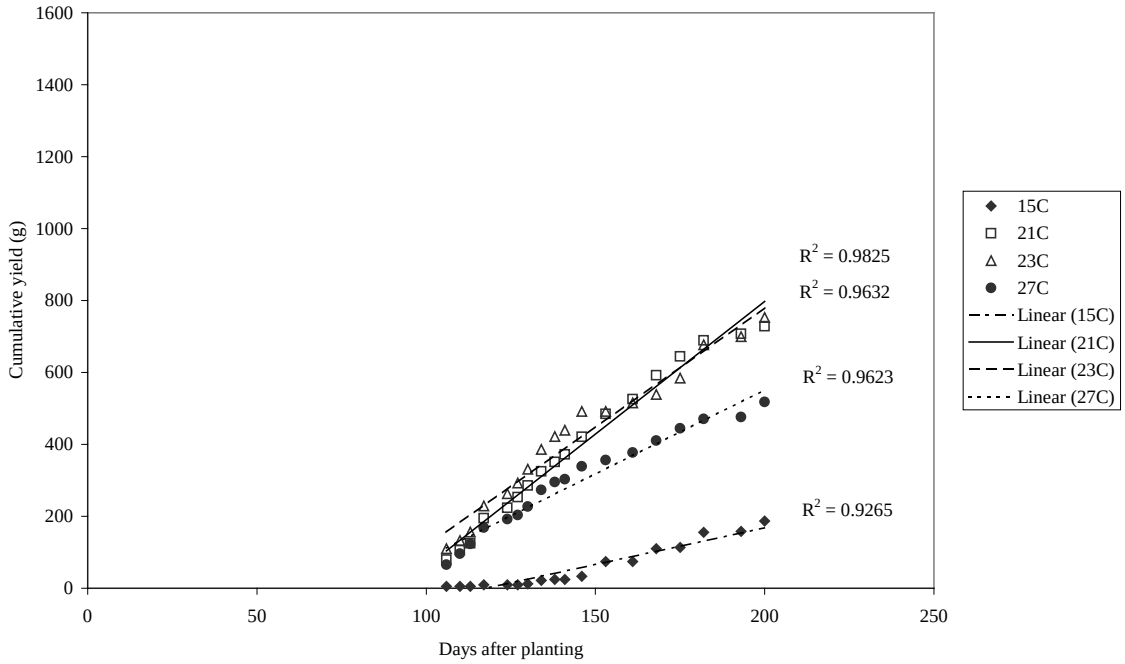


Figure 22. Cumulative yield (g), measured as fruit fresh weight per plant, between July and September 2001 (105 – 200 DAP) at four different temperatures at 50% shade. R^2 values show the fit of the linear regression lines described by the equations:
y = 2.0461x - 240.25 (15°C); y = 7.3824x - 678.72 (21°C); y = 6.6463x - 549.29 (23°C); y = 4.6842x - 384.64 (27°C).

The steepest slope can be observed for the 23°C treatment at ambient light, followed by the 27 and 21°C treatment. Under shade the 21 and 23°C treatment produced the steepest slopes, followed by the 27°C treatment. In both light treatments the lowest slopes were produced at15°C.

The establishment of a simple relationship between crop growth rate (gd^{-1}) and temperature (°C) was a vital step in the development of this model. The slopes of the linear regressions fitted to the cumulative yield data shown in Figures 16 and 17 were plotted against the average treatment temperatures.

Second order polynomials fitted the plotted data with R^2 values of 85 and 98% for treatments at ambient light and under shade respectively (Figure 23). At both light levels, the 21 and 23°C treatments showed the greatest divergence from the fitted line. The polynomial fitted to treatments at ambient light therefore slightly overestimated the growth rate at 21°C and slightly underestimated the growth rate at 23°C. The fit of the polynomial to the shaded treatment slopes was better, although the 21°C treatment was slightly underestimated and the 23°C was slightly overestimated by the fitted line.

The limited number of temperature points means the temperature-yield relationship established here is inevitably rather tentative. A broken stick function would predict temperature optima more accurately than the second order polynomial used here; more data-points would be required, however, to increase confidence in the temperature/yield relationship.

The second order polynomials calculated here enable the simulation of daily growth rates (gd^{-1}) for any given temperature between 15 and 27°C under ambient light conditions. A separate function gives cumulative yields for 50% shade. The lack of light as a variable within the model is a limitation that is being addressed in ongoing work (see 'Future modelling relationships and approaches').

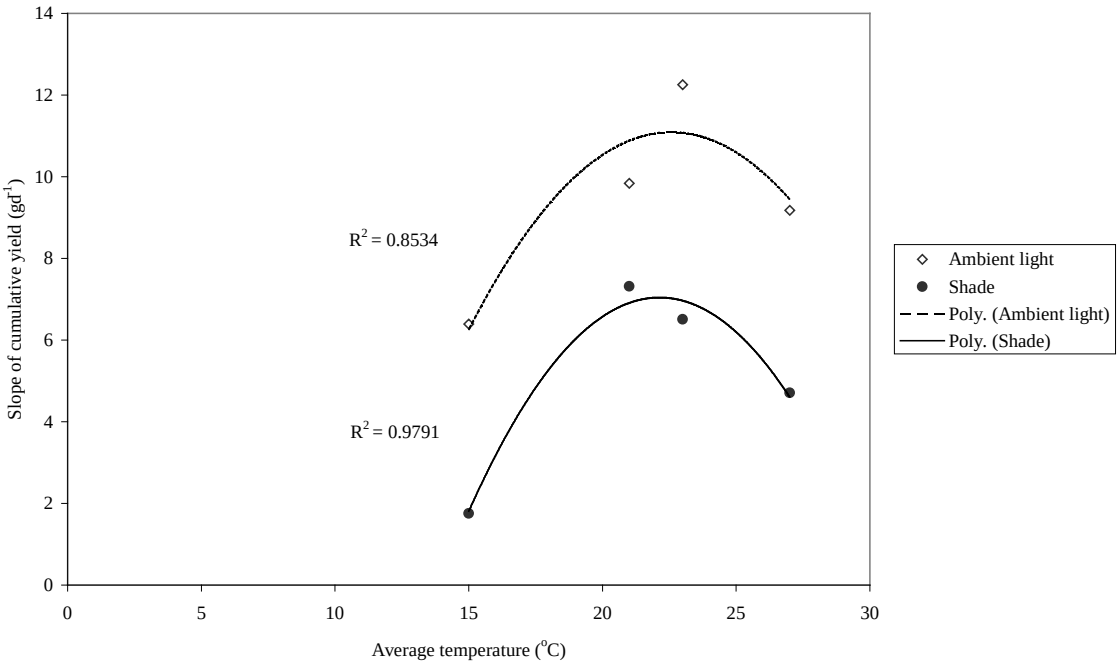


Figure 23. The fitted slopes of cumulative yield were plotted against average seasonal temperature across treatments. Two second order polynomials describe the relationships for ambient light: y = -0.0843x2 + 3.8044x - 31.846; and shade: y = -0.1029x2 + 4.5549x - 43.368. R^2 values show the fit of these to the data-points.

The starting value for the simulation of cumulative yield is crucial. Here, measured starting values at 105 DAP were used. To enable an accurate and independent simulation of starting values for the model, further datasets would be required to establish mathematical relationships. Alternatively, site-specific historical data could be employed to determine appropriate starting values.

Use of the Model for Crop Simulation

The model comprised of five calculations at any time-step.

A moving average of temperature (^oC) T was calculated as the average of the preceding 14 days and of the following 7 days. The use of the following 7 days allowed weather forecasts and/or site-specific historical weather data to be incorporated.

1. T at t_0 = ((Σ T at t_{-14} to t_0) + (Σ T at t_1 to t_7)) / 22 (^oC),
   t_0 specified the given day, t_{-14} fourteen days previous and t_7 seven days in advance (coming to a total of 22 days).

According to the moving average temperature, a growth rate (gd^{-1}), R, was then calculated at every time-step by using the relationships established in Figure 23 for ambient light and shade respectively. Second order polynomials gave:

2. $R_{ambient} = -0.0843x^2 + 3.8044x - 31.846$ (gd^{-1})
   $R_{shade} = -0.1029x^2 + 4.5549x - 43.368$ (gd^{-1})

This simulated growth rate, R, was summed above a specified starting value to simulate cumulative yield (g), C, for every day.

3. C at t_0 = C at t_{-1} + R at t_0 (g),
   where t_0 specifies the given day and t_{-1} the previous day.

The initial value for cumulative yield at t_{-1} (g) required the input of a starting value. This can be the actual measured cumulative yield for the crop up to this point (105 days after planting), as was chosen here, or it can be an average value based on historical data for the specific site.

A moving average growth rate (gd^{-1}), r, was calculated where,

4. r at t_0 = (r at t_0 + Σ r at t_1 to t_7) / 8 (gd^{-1})

This projection by seven days was possible as the moving average temperature incorporated a seven-day advance to t_7.

To enable a yield prediction fourteen days in advance, c, the known simulated cumulative yield, C, of the previous day was added to the multiple of the moving average growth rate, r, of that day:

5. c at t_{14} = C at t_{-1} (g) +(r at t_0* 15) (g)

The multiple of the moving average growth rate, r at t_0, extrapolated by seven days beyond the weather forecast information of step 4.

The predicted yields were then calculated for every day to enable a cumulative yield profile to be plotted for the season.

Model Testing

The model was tested against the dataset on which it was based (cumulative yield data of 2001). The simulated cumulative yield, C, was compared to the actual measured cumulative yield over the season in Figures 24 and 25. Actual daily temperature data were fed into the simulation for the entire season.

The general trends of the cumulative yields in the ambient light treatments were reflected by the simulated yield forecasts (Figure 24). The 23^{o}C treatment, although seriously underestimated, was simulated as the highest yielding treatment, while the 15^{o}C treatment was simulated as the lowest yielding treatment. The underestimation of growth rate at 23^{o}C, derived by the fitted polynomial relationship (Figure 23), systematically led to an underestimation of simulated cumulative yield in the 23^{o}C treatment. This could be overcome with the development of a more accurate temperature/yield relationship following the inclusion of further data sets (discussed above). The measured cumulative yields of the 21 and 27^{o}C treatments were between those of the 15^{o}C and 23^{o}C treatments and very similar to each other. Their simulated cumulative yields managed to describe the actual yields well, although, from 123DAP the 21^{o}C treatment slightly outperformed the 27^{o}C treatment in the model, whereas the opposite trend was found for the measured cumulative yields.

The simulated cumulative yield forecasts in the shaded treatments gave a better description of the measured yields (Figure 25), probably due to a more clearly defined temperature relationship (R^2 of 98%) (Figure 23). The start and end of growth were described particularly well. Mid-season,

around 150DAP, the simulated line departed from the actual observed values and underestimated cumulative yield of shaded plants at temperatures above 21°C by approximately 25%. At 15°C the reverse was the case, and the simulated values overestimated the actual measurements by approximately 50g per plant.

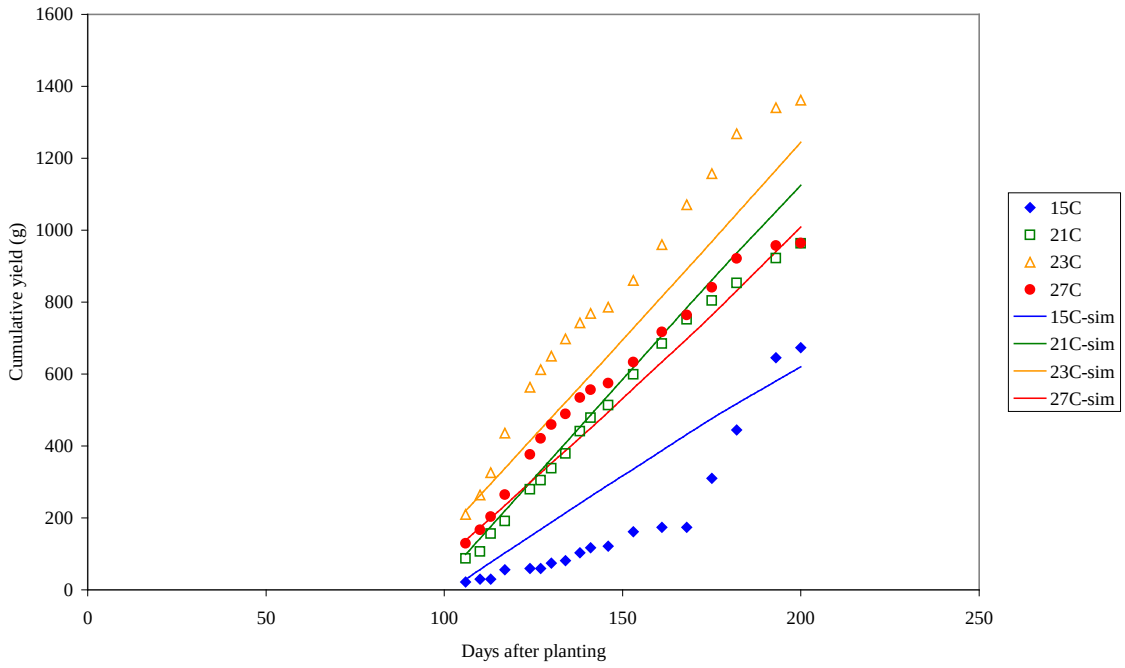


Figure 24. The simulated cumulative yield (g) forecasts of the temperature treatments at ambient light in comparison to the actual measured yield. Simulated and actual yields are shown in the same colour. The model is based on a moving average temperature and growth rate.

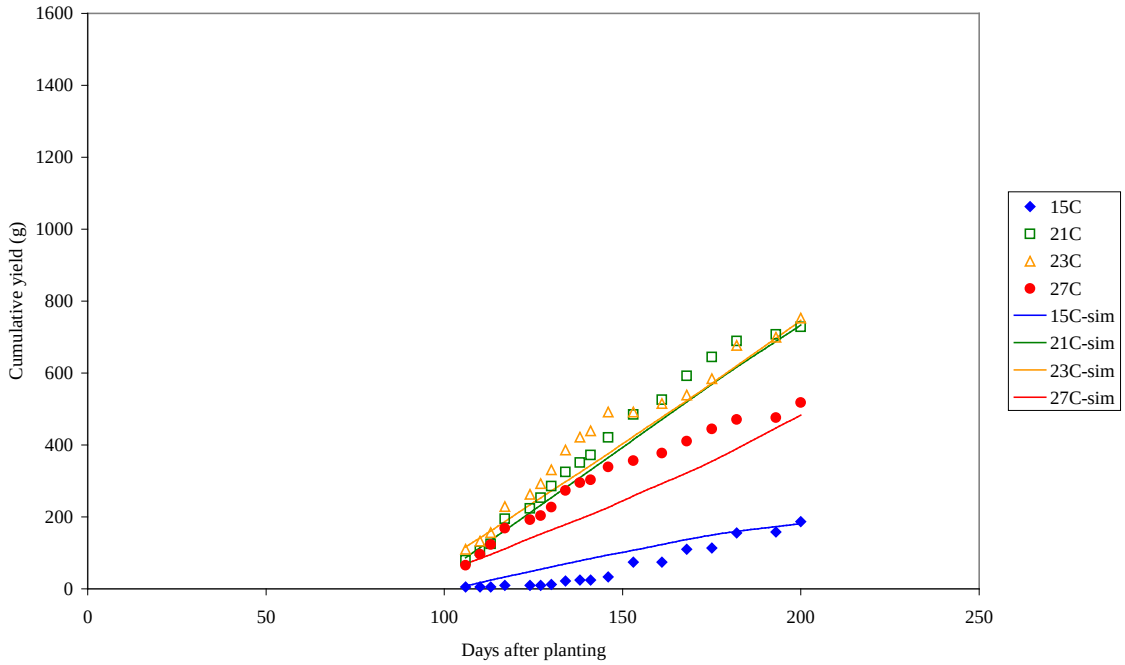


Figure 25. The simulated cumulative yield (g) forecasts of the temperature treatments under shade in comparison to the actual measured yield values. Simulated and actual yields are shown in the same colour. The model is based on a moving average temperature and growth rate.

The simulated total cumulative yield forecasts were plotted against the actual measured cumulative yields to evaluate their fit alongside a one to one regression (Figure 26). The overall fit was good, but at higher yield values, the yield was overestimated by 161g per plant (21^{o}C treatment) and was underestimated by 116g per plant (23^{o}C treatment). This equates to an overestimation of 16.7% and an underestimation of 8.5% in these two treatments respectively. The average divergence of the simulated cumulative yields from the actual measured cumulative yields was 6% across the temperature and light treatments.

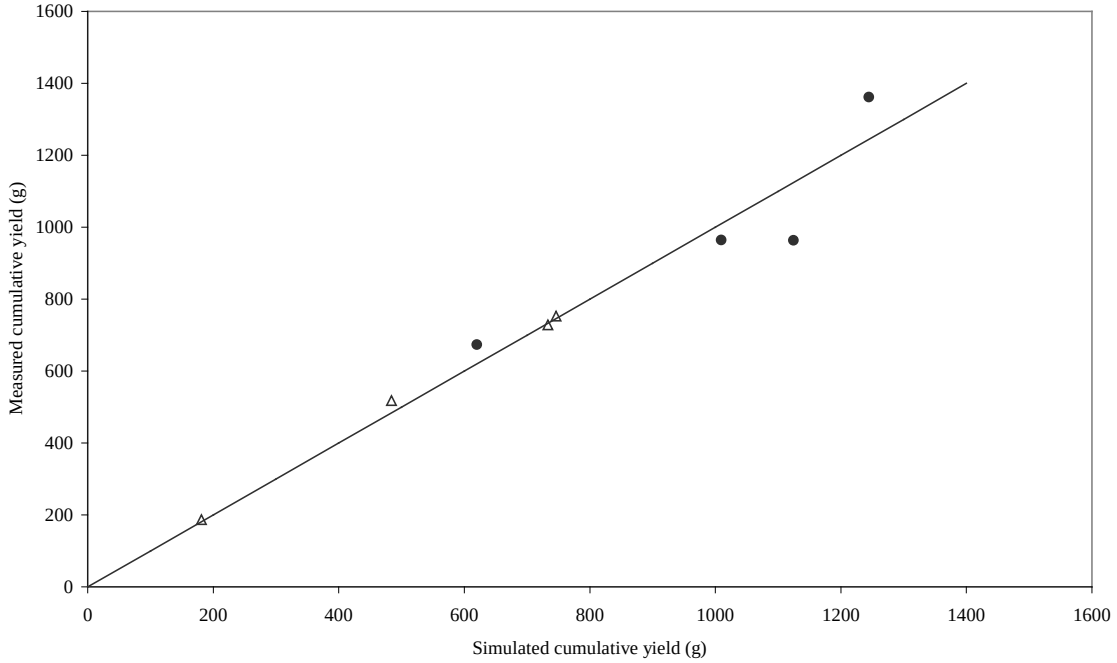


Figure 26. Simulated total cumulative yield forecasts (g) plotted against the recorded cumulative yields (g). A one to one regression aids the interpretation of the data-points, where those situated on the line signify a perfect fit of the model. Open triangles show yields simulated/grown under shade and closed circles show yields at ambient light.

The accuracy of the 14-day cropping forecasts was tested against the simulated yields for that day. As expected, the fourteen-day cropping forecasts were in excellent agreement with the simulated cumulated yields, as the former was based on a simple multiple relationship of the latter. This can be seen in Table 1, as the fitted linear regressions across treatments had slopes of close to one.

Table 1. Slopes of cumulative yield forecasts against daily simulated cumulative yield (g) under light and shade for 15°C, 21°C, 23°C and 27°C:

Treatment	Ambient light	Shade
15°C	y = 1.0016x - 0.0538 (R^2 = 1)	y = 1.0062x - 0.117 (R^2 = 0.9996)
21°C	y = 1.0015x - 0.7245 (R^2 = 1)	y = 1.0025x - 0.9354 (R^2 = 1)
23°C	y = x - 0.1673 (R^2 = 1)	y = 0.9996x - 0.1403 (R^2 = 1)
27°C	y = 0.9995x - 0.2519 (R^2 = 1)	y = 0.9988x - 0.366 (R^2 = 0.9997)

Model Validation and Discussion

The control treatments of 2002 and 2003 were chosen to validate the model, as these treatments were close to a commercial production system. A major difference between the dataset used for model development and these from 2002/3 used for validation was the day/night temperature differential in the latter, in which the glasshouse was kept at an ambient temperature. The treatments used in model development, in contrast, were temperature controlled to maintain the same temperature over 24-hours (i.e., the plants were not subjected to a temperature differential).

Cumulative yields in 2002 were higher than in 2003 from 167 days after planting (Figure 27). In 2003 yields dipped from this point onwards, whereas cumulative yields continued to increase at the same rate until the end of the season in 2002. The total cumulative yield in 2002 was 1713g per plant and in 2003 was 1180g per plant.

The average daily temperature differential was 12^{o}C in both 2002 and 2003 (Figure 28). The seasonal average temperatures were 21^{o}C in 2002 and 22^{o}C in 2003 between July and September. However, a period of exceptionally high temperature between 140 and 152 DAP occurred in 2003. This coincided with the hottest day on UK records, the 10th August.

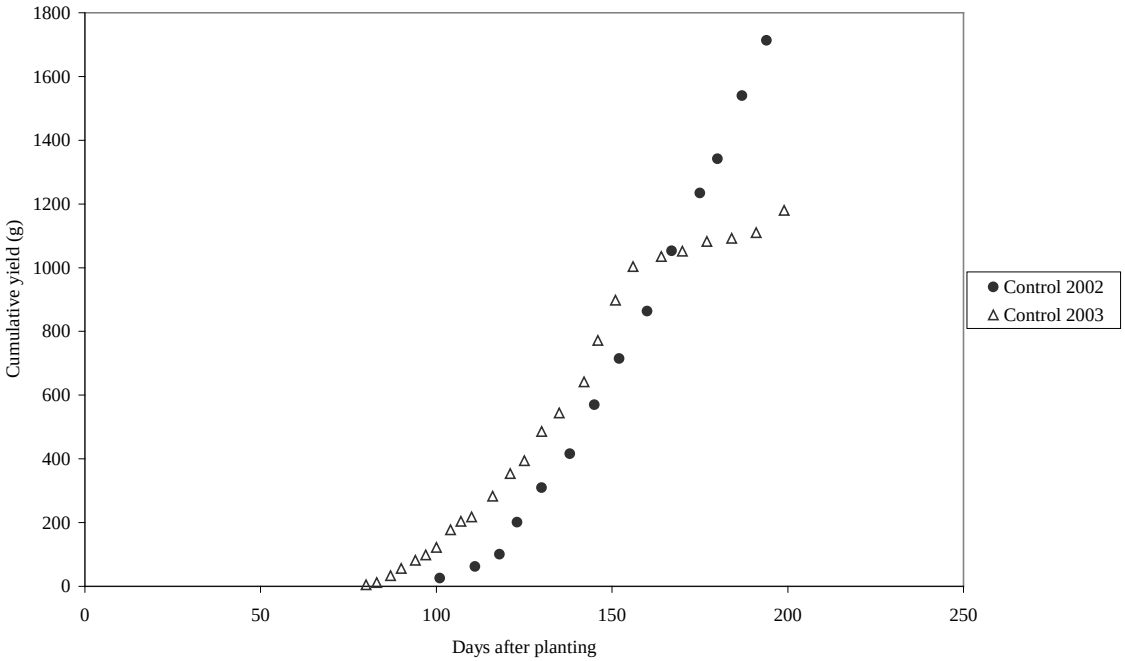


Figure 27. The cumulative yields (g) of the control treatments in Experiment 7 (2002) and 8 (2003).

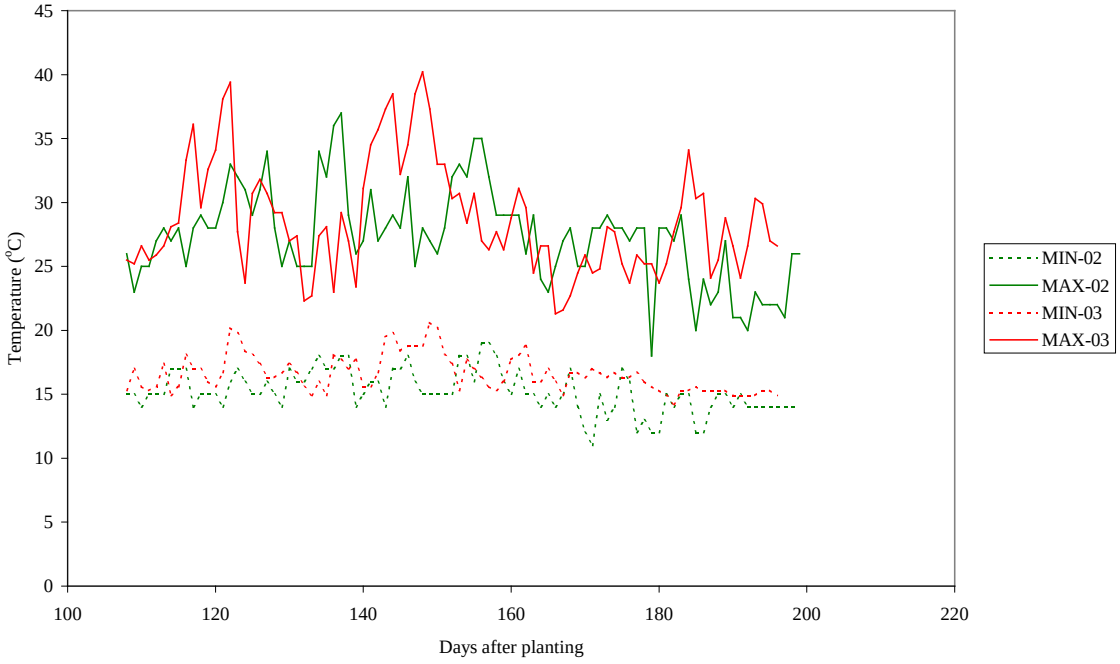


Figure 28. Daily minimum and maximum temperatures for the period between July and September 2002 (green) and 2003 (red).

The cumulative yield simulation and the 14-day forecast increasingly underestimated the actual cumulative yields in 2002 from approximately 145 DAP (Figure 29).

The simulation gave a better fit and prediction of the 2003 data (Figure 30). Similar to the 2002 dataset, the simulation underestimated the actual measured cumulative yields from approximately 146 DAP. Mid-season this underestimation increased to approximately 230g per plant. In contrast to the 2002 data, a decline in actual cropping rate from about 164 DAP meant that the model simulated the cumulative yields at the end of the season well.

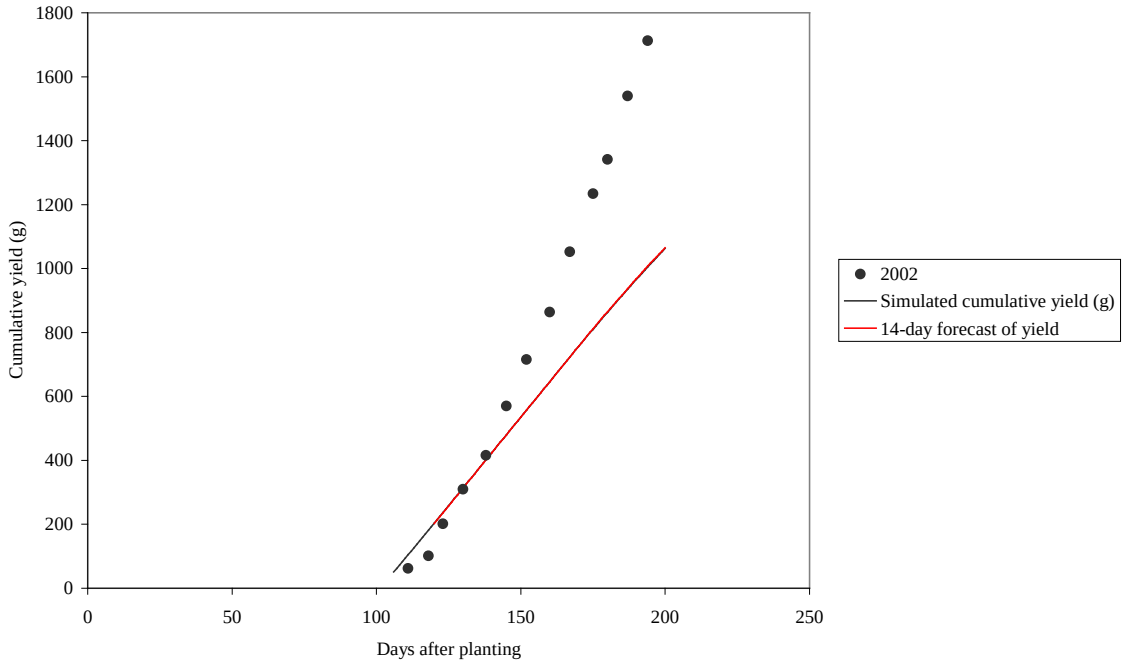


Figure 29. Measured cumulative yields of the control treatment in Experiment 7 (2002) shown with the simulated cumulative yields (black line) and the 14-day yield forecast (red line), based on a moving average temperature (2002) and a moving average growth rate for cumulative yield.

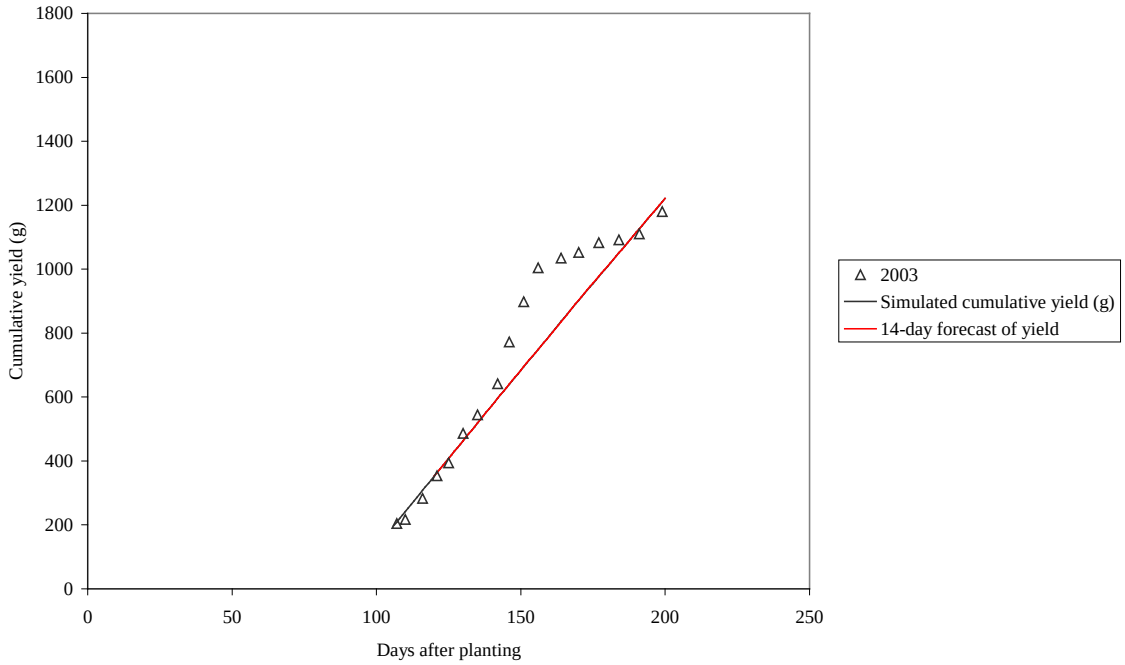


Figure 30. Measured cumulative yields of the control treatment of Experiment 8 (2003) shown with the simulated cumulative yields (black line) and the 14-day yield forecast (red line), based on a moving average temperature (2003) and a moving average growth rate for cumulative yield.

The average maximum temperature for the twelve-day period between 140 and 152 DAP in 2003 was 35^{o}C, which was matched with a high average minimum temperature of 18^{o}C during nights. Experiments 7 and 8 demonstrated a transfer of 5-days into a high temperature environment to be capable of inducing thermo-dormancy. A reduced rate of cropping could therefore be expected from approximately 14 days following the first week of high temperature exposure, i.e. from 161 DAP. Figure 25 shows that cropping was reduced from approximately 164 DAP, indicating high temperatures to be responsible for the reduction in yield. At present the model is not capable of predicting heat induced cropping troughs. This could be achieved by tuning the existing model to further data-sets from commercial production sites, which is a vital step in model improvement. A maximum and minimum temperature would be required for every day, to enable insight into the day/night temperature differential of the specific data-set described; the results of experiments 7 and 8 would aid the interpretation of physiological processes. Ongoing work is looking at the possibility of including historical data, collected on 'Everest' grown at The University of Reading over the past years, from other research projects. The addition of a further loop to the model would relate dips in cropping to maximum and minimum temperatures experienced fourteen days

previously. It would also permit the prediction of increased yields under non-stressed conditions, as found in a natural environment with cool night temperatures. This is an urgently needed piece of work, with the addition of which the simulation of the 2002 and 2003 data would improve by an increase of cumulative yields, in particular mid-season, and a decrease of cumulative yields following periods of high day/night temperatures.

Similar modelling relationships to those used here have been used for the simulation of harvest index increase in relation to temperature in annual crops of peanut (Hammer *et al*., 1995) and for the simulation of harvest index increase in relation to soil moisture in field bean (Angenendt, 2001). These were more successful than the model presented here, due to the availability of a greater number of data points. An important difference can be found in the physiological nature of the crops. In the bean and peanut models harvest indexes describe actual rather than cumulative values. The complex perpetual fruiting patterns of 'Everest', with peaks and troughs across the season have previously been described and discussed in the Annual Reports 2000-2003. For use in the model cumulative yield was chosen, effectively to enable the description of a simpler growth pattern. This does mean, however, that sensitivity towards sudden changes in cropping is reduced.

Future Modelling Relationships and Approaches

Ongoing work is evaluating a modelling approach, in which the data-points of Figure 18 are combined to give two-dimensional models with two multiple-regressions. Yield would then be a function of both temperature and light. One regression would calculate cumulative yields up to a temperature optimum, and the second regression would calculate cumulative yields beyond this temperature optimum. This requires each data-point across temperature and light treatments to be allocated to either regression one or two, with the use of residual sums of squares. This approach would be beneficial, due to the incorporation of light as a driving variable. The shift in temperature optima depending on light integral means, however, this procedure is more complex than anticipated.

In conclusion, the model developed here demonstrates the possibility of a simulation and prediction of cumulative 'Everest' yields over the season. Three adjustments are needed before this model could be used within a commercial production system:

1. The addition of further, commercial, datasets to improve the accuracy of the mathematical relationships established here. This would also enable light to be incorporated as a driving variable in the model next to temperature.

2. Analysis of the daily maximum and minimum temperatures of the datasets from 1. to enable the 14-day forecast of heat-induced dips in cropping, caused by thermo-dormancy.

3. The datasets from point 1. would enable the independent simulation of starting values for cumulative yields. This would facilitate an entire yield simulation for any site-specific temperature data.

Finally, a user-friendly, windows based software could be established based on the model. A 'beta-version' of this would be used and tested on specific sites, before tuning to allow the production of a finished 'alpha-version' for wider use as a decision support tool.

Experiments Reported Under other Objective Descriptions of the Final Report

Optimization of Junebearer Planting Material: Test Conditions for Inducing Two Flowering Periods (Task 1.6)

As this is essentially a chilling experiment, the description of work conducted under Task 1.6 has been included under Objective 4, although in the HORTLINK work programme it forms part of Objective 1 (note section 'Objective 4', Experiment 2).

Develop and Refine the Model Relating Fruit Flavour to Water Stress (Nottingham/ADAS) (Task 1.10)

This task was revised, as water stress was found to have no significant effect on fruit flavour improvement (detailed in the Interim Report – Year 3, pg.42). The revised task was included under Objective 2 to: *Test the Hypothesis that solar irradiation levels on the ripening fruit affect flavour*.

RECOMMENDATIONS FROM OBJECTIVE 1

To allow for controlled flower production of the strawberry plant that will sustain long season cropping of Class 1 fruit with optimum flavour characteristics, recommendations are given for its water, light and thermal environments.

Recommended Water Environment

- Water stress had no significant effect on improving fruit flavour.

- Irrigation could be controlled and optimised, in principle, by a computer-controlled weighing system, as tested in experiment1.

Recommended Light Environment

- Optimum light quantity is required for maximum fruit flavour (reflective films, lights etc.) (note also Objective 2).

- Optimum light quantity is required for achieving the full potential for crown numbers, vegetative and reproductive growth, thus enabling maximum yields (temperatures permitting). Supplementary lighting may, therefore, be beneficial for out-of-season glasshouse production of 'Everest'.

- Flower initiation in 'Everest' was found to be photoperiod insensitive.

Recommended Thermal Environment

- A temperature environment of 23^{o}C was found to be optimal for yield in 'Everest', thus suggesting a higher temperature optimum than for the Junebearer 'Elsanta' (15^{o}C).

- A lower temperature limit was found to be 15^{o}C, as temperatures of 21, 23 and 27^{o}C proved ideal for assimilate partitioning to fruit. This means that the amount of assimilates partitioned to reproductive growth in these warmer temperatures was in proportion to vegetative growth (source capacity). At 15^{o}C, in contrast, vegetative growth was favoured in 'Everest'.

- A temperature environment below 26^{o}C is recommended for 'Everest', to avoid reduced cropping due to heat stress (this might be achieved by using heat-reducing polythenes).

- It is recommended that exposure of plants to day-time temperatures of 26^{o}C and above should be balanced with cool night temperatures to reduce the occurrence of thermo-dormancy in the everbearer (e.g., by use of heat-reducing and heat-emitting polythenes, improved venting and air circulation - to allow stored heat and long-wave radiation to escape during the night).

OBJECTIVE 2

Provide a Quantitative Description of Resource Partitioning between Vegetative and Reproductive Growth

Introduction

Assimilate partitioning between vegetative and reproductive growth is a major factor in determining the yield and quality of many fruit crops. The aim of objective two was to assess the influence of assimilate availability on strawberry fruit quality as measured by the development of fruit flavour compounds and by taste panel assessment. The results reported in this section should be considered alongside the experiments reported under objective 1 which investigated the analysis of fruit flavour and the influence of controlled water stress on fruit flavour expression.

Data from strawberries and other fruits (Brauss *et al* 1998, Gaillard *et a*l 1977 Watson *et al* 2002)) have shown that there is considerable fruit-to-fruit variation in flavour within a crop. Several workers have demonstrated flavour differences between crops grown at different seasons (Proebsting and Mills 1981, De Bruyn *et al* 1971, Wrolstad and Schallenberger 1981), at different locations (Rosenfeld *et al* 1998, Wrolstad and Schallenberger 1981) and from pick to pick within a single crop (Watson *et al*). Shaw (1990) determined that the soluble solid content of strawberry fruit was more dependent on environmental conditions during production than on the genetic make-up of the plant. Kader (1991) showed that fruit from summer-planted strawberries had a higher soluble solid content and titratable acidity than winter planted fruit. From a fruit quality and marketability viewpoint, it is very important to consider fruit-to-fruit variation in flavour. This is because quality assurance tests are often based on the mean quality of a representative sample. Consumers judge the flavour quality of individual fruits, so although the mean quality of a strawberry crop may be good, a high variability within the crop may mean that a significant number of strawberry fruit may be unacceptable to consumers. Significant variation in flavour from pick-to-pick can compound this situation further as consumers may experience wide differences in flavour from week to week, resulting in disappointment with a specific cultivar and affecting ‘brand’ loyalty.

Strawberry flavour is a complex interaction between a large number of volatile and non volatile compounds. The non volatile compounds e.g. sugars and acids are responsible for the sweetness and tartness of the fruit and may also have an important role in the perception of the volatile compounds which are central in producing the distinctive fruity flavour. Since these compounds require energy for synthesis the level of photosynthesis in relation to fruit load might be expected to play a large part in their expression in the fruit.

Quite a large body of data exists on the effects of shading on the flavour quality of a number of fruit species. The majority of this work focuses on orchard fruit with the aim of targeting canopy pruning and fruit thinning strategies (Garriz *et al* 1998, Palmer *et al* 1997, Marini *et al* 1991). There has been little study into the effect of shading on strawberry flavour compounds. Mapping the response of strawberry flavour to changes in environmental conditions, such as light, is an important step in understanding possible reasons for the variability in the flavour of the crop. Such an understanding may give growers the potential to manipulate fruit flavour quality by managing the growth environment, with the aim of producing fruit of a more consistent flavour and quality throughout a single crop and from season to season.

Analysis of strawberry volatile compounds is problematic because of the high metabolic rate of the fruit (Perkins-Veazie 1995, Abeles and Takeda 1990). Volatile content. Flavour changes can occur rapidly after picking so there is a need to carry out volatile flavour analysis quickly. The technique of Atmospheric Pressure Chemical Ionisation (APCI) is ideal, allowing all the volatiles present in a sample to be measured simultaneously within a couple of minutes (Brauss *et al* 1998).

It is common for growers to measure the soluble solid content of fruit using refractometry, as it represents a quick and portable method for the determination of total sugar content under field conditions. There are problems associated with the use of the refractometer. The method is accurate only for pure sucrose solutions, requires temperature calibration and uses a non-linear scale which is difficult to work with (Southgate 1976). Insoluble solids are known to interfere with the determination of refractive index (Joslyn 1970). Refractometer readings are also

affected by the number, mass and chemical structure of the dissolved particles (Chadha 2001). By using liquid chromatography – mass spectrometry (LC-MS), these problems can be avoided and a clearer picture as to the relationship between individual components making up the sweetness or tartness of a fruit can be achieved.

Using the techniques discussed above the aim of this section was to consider the influence of sink strength (achieved by flower thinning) and source strength (achieved by canopy shading) on fruit flavour quality. The first experiment manipulated both source and sink using two cultivars. The results of the first experiment showed that sink manipulation had little effect but that source manipulation had a significant effect on both volatile and non-volatile flavour components. In addition there was also a large between harvest variation in these compounds. To investigate this further a second experiment using only one cultivar was carried out and no flower thinning was used. In addition an experiment was carried out to if fruit shading alone influenced fruit flavour compounds.

Experiment 1. Resource partitioning and fruit quality: source and sink manipulation

The full report of this experiment can be found under task 2.1 in the second year annual report.

Materials and Methods

Plant Growth Conditions

‘ Elsanta ‘ and ‘Everest’ Strawberry plants were planted in 0.5 m peat bags on 02/04/01. Five plants were established in each half bag with 16 bags for each level of shading. The plants were arranged as a randomised block design with four replicates of each treatment. The glasshouse was set to heat at 8°C and vent at 12°C. The plants were grown in natural light. Plants were kept well-watered throughout the experiment via a drip irrigation system.

Experimental Treatments

Canopy source strength was manipulated by three shade treatments (0%, 25% and 47% shade). Fruit sink strength was manipulated by removing 30% of developing flowers. Shading treatments were imposed 1 week prior to 1st ripe fruit for 2 weeks (05/06/01 – 19/06/01 for 'Elsanta', 14/06/01 – 28/06/01 for 'Everest'), after this time all plants were exposed to full ambient light.

Flavour Analysis

Ripe berries were harvested 5 times during the fruiting period (08/06/01, 11/06/01, 13/06/01, 17/06/01, and 20/06/01) and analysed for sucrose, glucose/fructose, citric acid content and 13 volatile compounds (see year 1 annual report). Eight berries from each treatment were used in each analysis. All berries were of a similar size and maturity, and were picked and analysed for volatiles on the same day. Non volatiles were measured later from frozen fruit.

A hedonistic taste panel was carried out on 'Elsanta' fruit harvested on 15/06/01.

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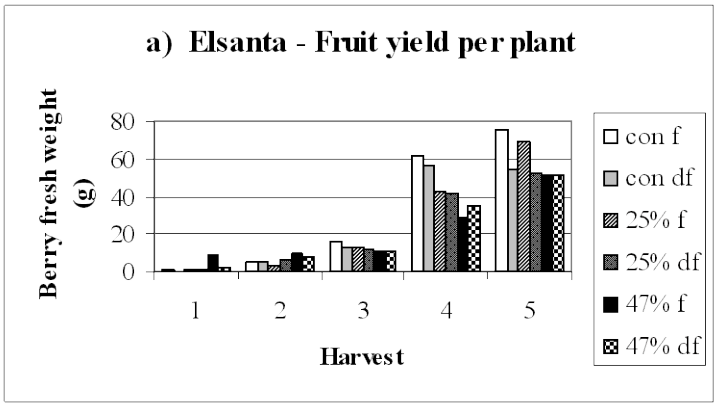
Yield measurements

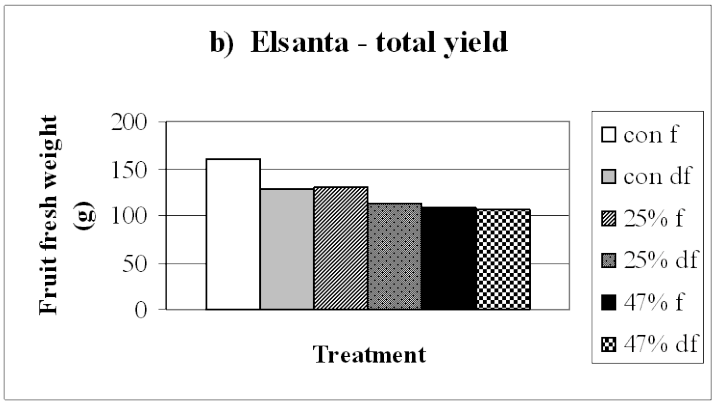
Ripe berries were harvested twice weekly throughout the experiment. The number of berries per plant was recorded, and berry weight and dimensions measured.

Results and Discussion*Yield*

- Shading resulted in a significant reduction of total yield per plant over the duration of the experiment; In 'Elsanta'(Figure 31) the yield per plant was reduced by around 50g (30%) in the 47% shade treatment compared with 0% shading. In 'Everest this loss was much smaller (10%) but from a lower total yield.

- Flower thinning reduced yields by 20% in 'Elsanta'.





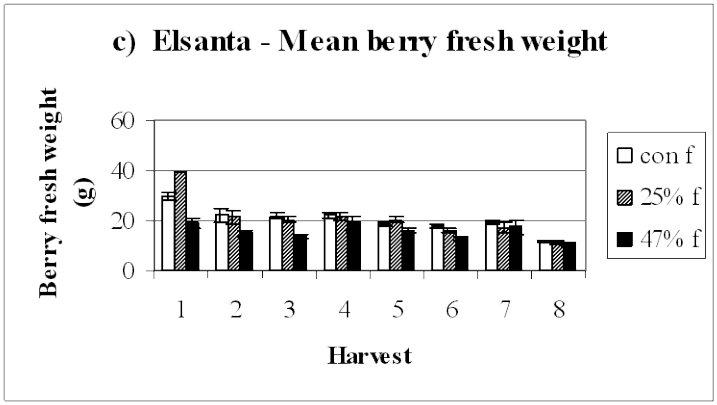


Figure 31. Yield measurements. a) Average total fruit yield per plant at each harvest for cv 'Elsanta' as influenced by shading/deflowering. Data derived by combining results from bi-weekly harvests. b) The effect of shading/deflowering on average total fruit yield per plant over the duration of the experiment. c) Mean Elsanta berry fresh weight per harvest as influenced by shading.

Volatiles

- *Pick-to-pick variation.* All of the volatile compounds tested in this study showed highly significant differences with harvest date. These differences were greater in 'Everest' compared to 'Elsanta' (Figures 32 & 33).

- *Effect of experimental treatments.* Hexanal, Hexenal, Ethylmethylbutyrate and Methylbutyrate showed a significant difference between shading treatments. In general, increasing the amount of shading decreased the amount of volatile present in the headspace. There was no significant effect of deflowering on volatile concentration in either cultivar.

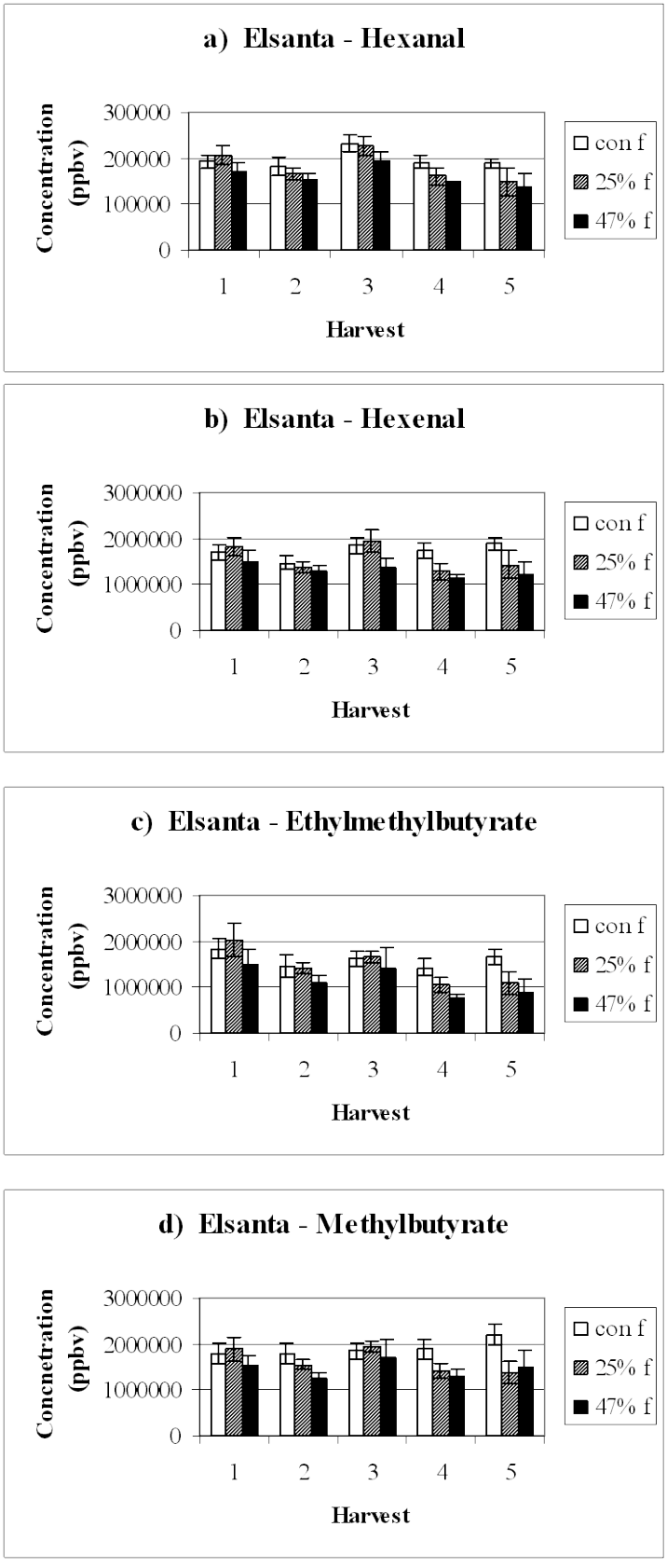


Figure 32. Mean volatile concentration with harvest for control and shaded 'Elsanta'. a) Hexanal, b) Hexenal, c) Ethylmethylbutyrate, d) Methylbutyrate.

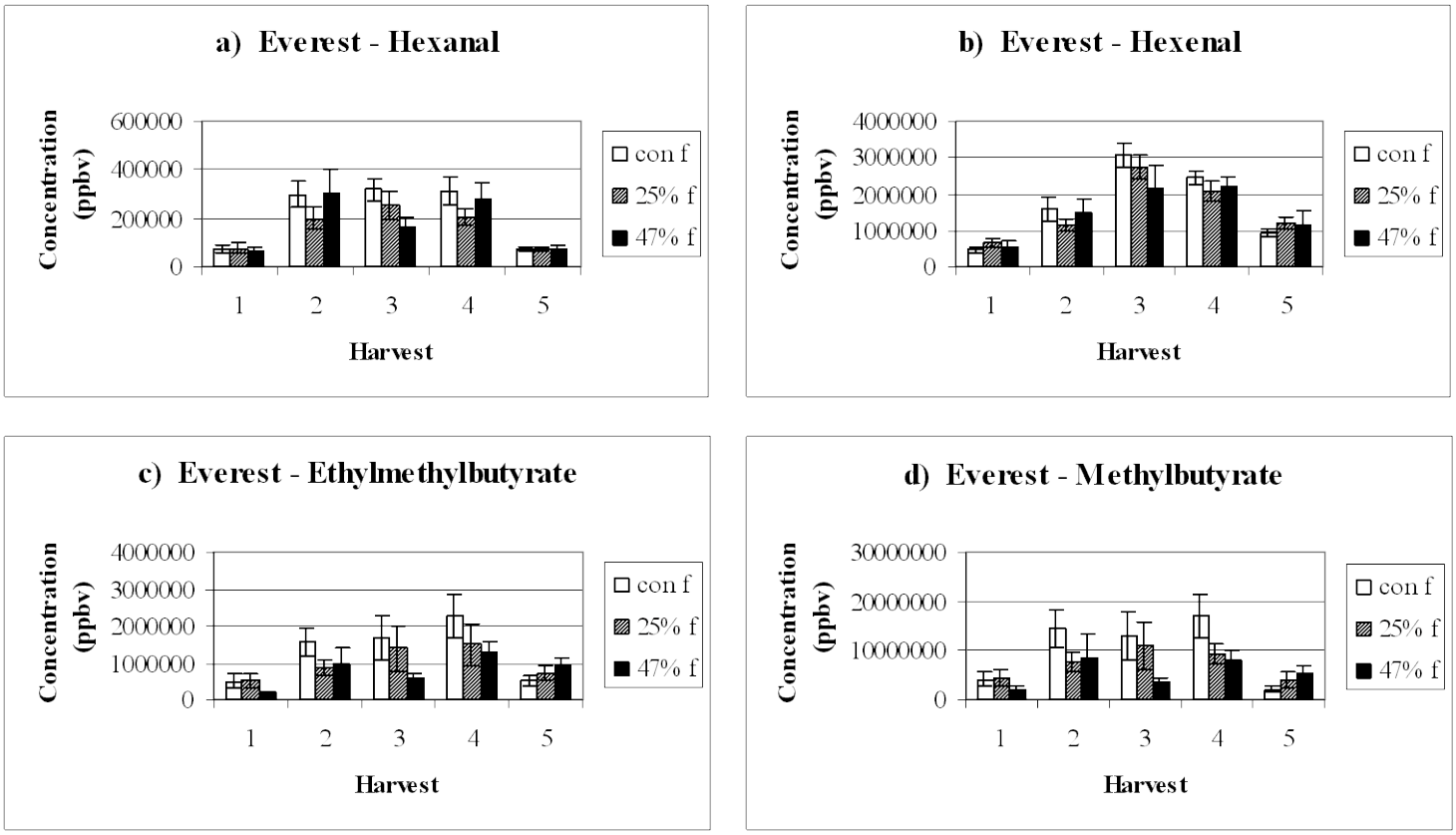


Figure 33. Mean volatile concentration with harvest for control and shaded plants 'Everest'. a) Hexanal, b) Hexenal, c) Ethylmethylbutyrate, d) Methylbutyrate.

Non-volatiles.

- *Pick-to-pick variation.* Sucrose, glucose and citric acid showed significant differences with date of harvest. 'Elsanta' sucrose concentration showed a steady decrease throughout the harvest period whereas glucose and citric acid showed less clear trends (fig 34). In 'Everest,' all the measured non volatiles tended to increase up to the third harvest then decrease.

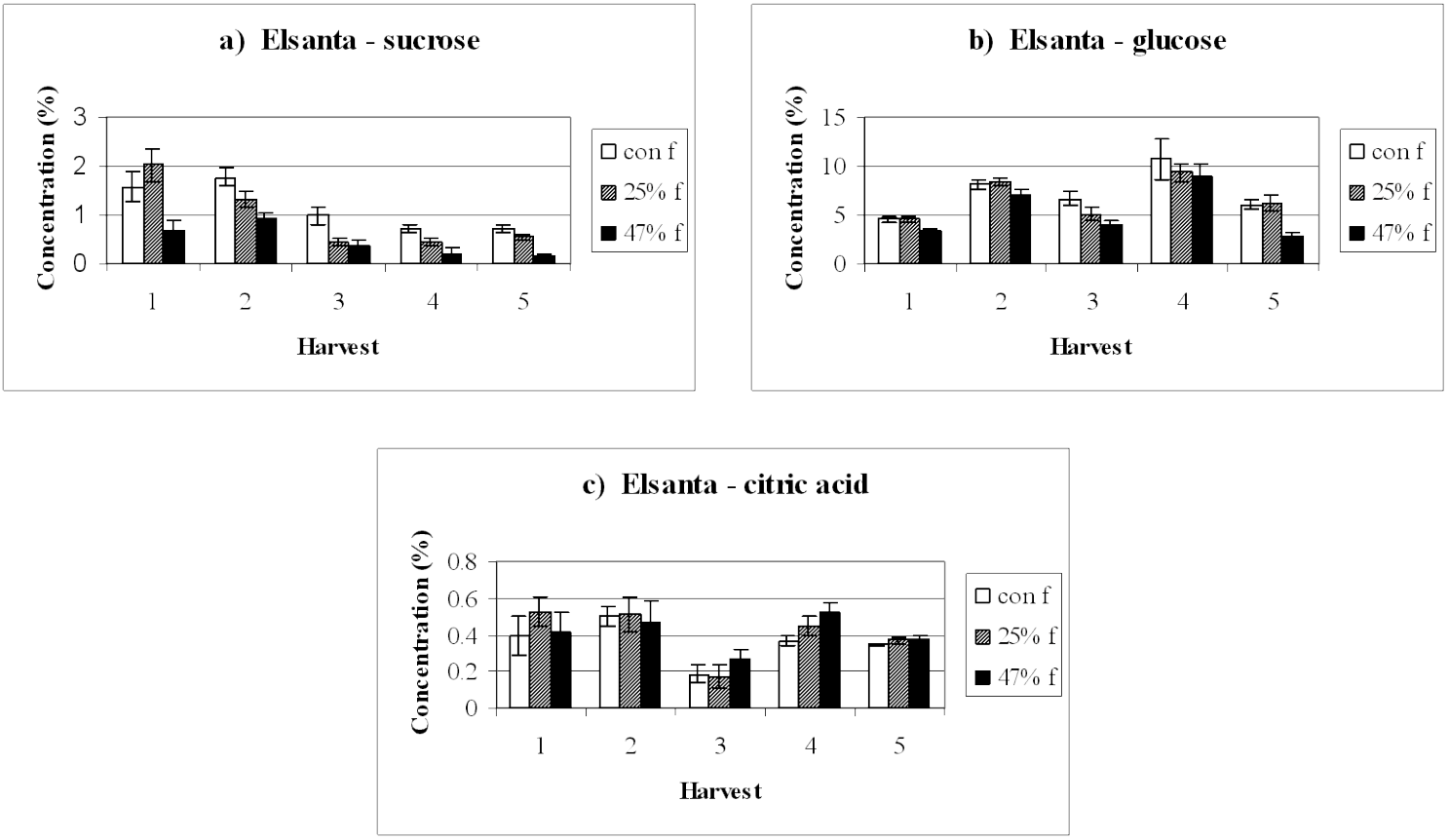


Figure 34. Mean non-volatile concentration with harvest for control and shaded 'Elsanta'. a) Sucrose, b) Glucose, c) Citric acid. Figure 35d shows the effect of deflowering on sucrose concentration at 47% level of shading.

- *Effect of experimental treatments* Shading had a significant effect on the concentration of sucrose and glucose in general, the sucrose and glucose concentration was inversely proportional to the level of shading. Citric acid levels in 'Elsanta tended to be lower in the non shaded treatments but there was no clear trend in 'Everest'. Deflowering tended to slightly increase the level of sucrose in 'Elsanta' at all levels of shading but there were no such effects in 'Everest'.

- *Taste panel.* The hedonistic taste panel was unable to identify differences in flavour between treatments.

Discussion

- Source manipulation (i.e. shading) had a major effect on fruit flavour compounds reducing the level of some fruit volatiles and sucrose and glucose, the results on citric acid levels were less clear. These measured differences could not be picked up by the use of a hedonistic taste panel.

- In both cultivars date of harvest had a highly significant influence on the concentration of both volatiles and non volatile compounds. In 'Elsanta' shading appeared to influence volatiles more than harvest date while in 'Everest' the reverse was true.

- Sink manipulation had little effect although sucrose levels tended to be increased in 'Elsanta' by flower removal. The total yield per plant over the period of the experiment were very different between the two cultivars with 'Elsanta' producing 25% more fruit than 'Everest' (reflecting the everbearing nature of 'Everest') so sink load in 'Everest' was already low and flower removal might be expected to have little effect.

- The observed reduction in sucrose levels over time in 'Elsanta' may be related to the measured increase in yield (sink strength) over this period which was large (Over 70g fruit per plant) compared to the influence of deflowering.

Experiment 2. Resource partitioning and fruit quality: sink manipulation

Materials and Methods

The full report of this experiment can be found under task 2.2 in the third year annual report

Plant growth conditions

The experiment was set up as a randomised block design with three replicates of each treatment. Ten 'Elsanta' plants were established in each full growing bag with four bags per replicate. The 'Elsanta' were planted on 21/03/02. First fruit was harvested on 20/05/02 and plants were harvested twice a week until the final harvest on 09/06/02. Fruit was weighed at each harvest to measure yield. Watering was by drip irrigation, moisture content of the peat bags was measured using a theta probe. The bags were kept well watered and no significant differences were found between peat bag moisture levels.

Experimental treatments

Three levels of shading were applied to the crop 0%, 47% and 73%. The shades were imposed one week prior to first ripe fruit and left in place for 12 days. After this the shading was removed and all plants received ambient light conditions

Flavour Analysis

Volatile and non volatile compounds were measured in the same way as experiment 1. Six berries per plot were used giving a total of eighteen berries per treatment. Two types of taste panel were carried out, the hedonistic taste panel (see experiment 1) was used for fruit

harvested on 25/05/02 and trained taste panels employed for fruit from the third and fourth harvest (see year 3 annual report).

Results and discussion

Yield

- As a general trend shading reduced yield although this was only significant at the third harvest. There were minimal yield differences between the two shaded treatments (Figure 35)

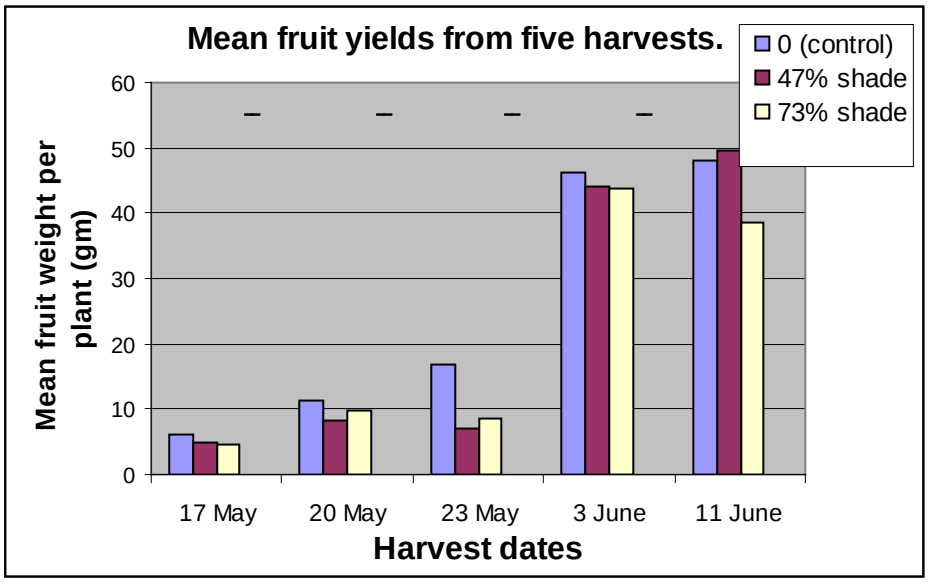


Figure 35. Average strawberry fruit yields per plant (gm) by treatment over five harvest dates.

Flavour analysis

- As found in experiment one volatile compounds showed highly significant differences with harvest date. Increased shading generally decreased the amount of volatiles present apart from methyl acetate which showed higher concentrations under 73% shading during the first three harvests (Figure 36).

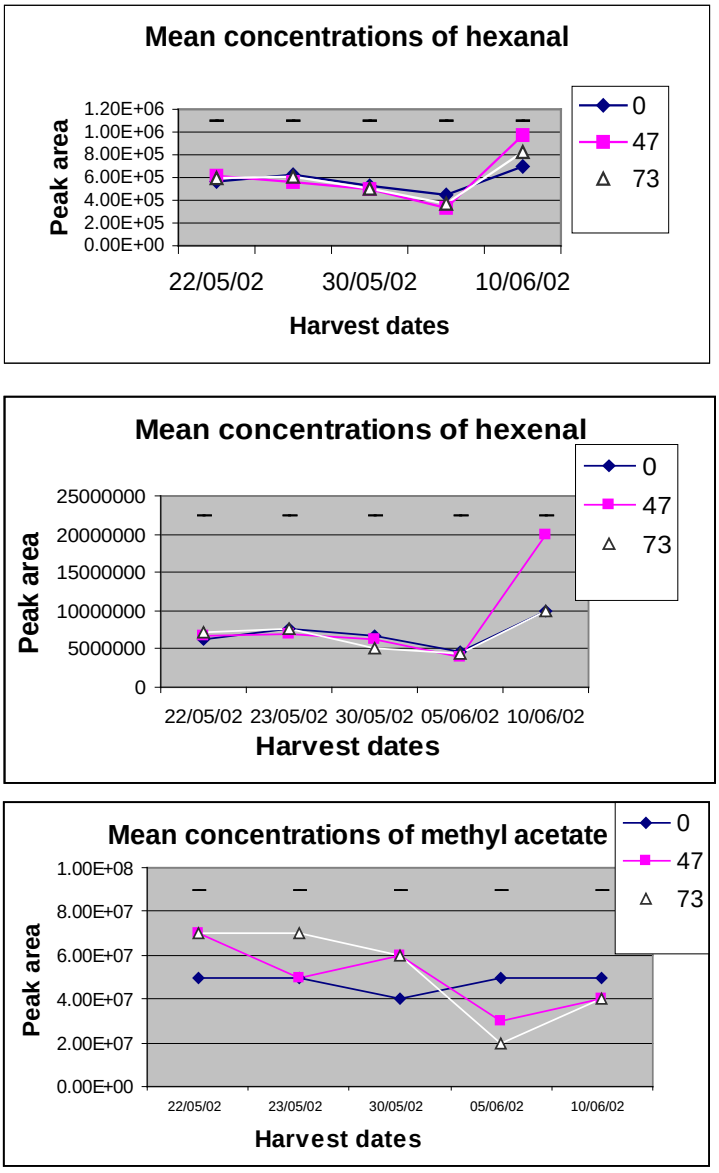


Figure 36. The influence of shading on selected mean volatile concentrations in 'Elsanta'.

- Citric acid showed highly significant effects of harvest date tending to decline over time with little influence of shading. Sucrose levels tended to remain fairly stable when no shading was applied however shading significantly decreased the sucrose level during the first three harvests. The response of glucose levels was similar to sucrose (Figure 37).

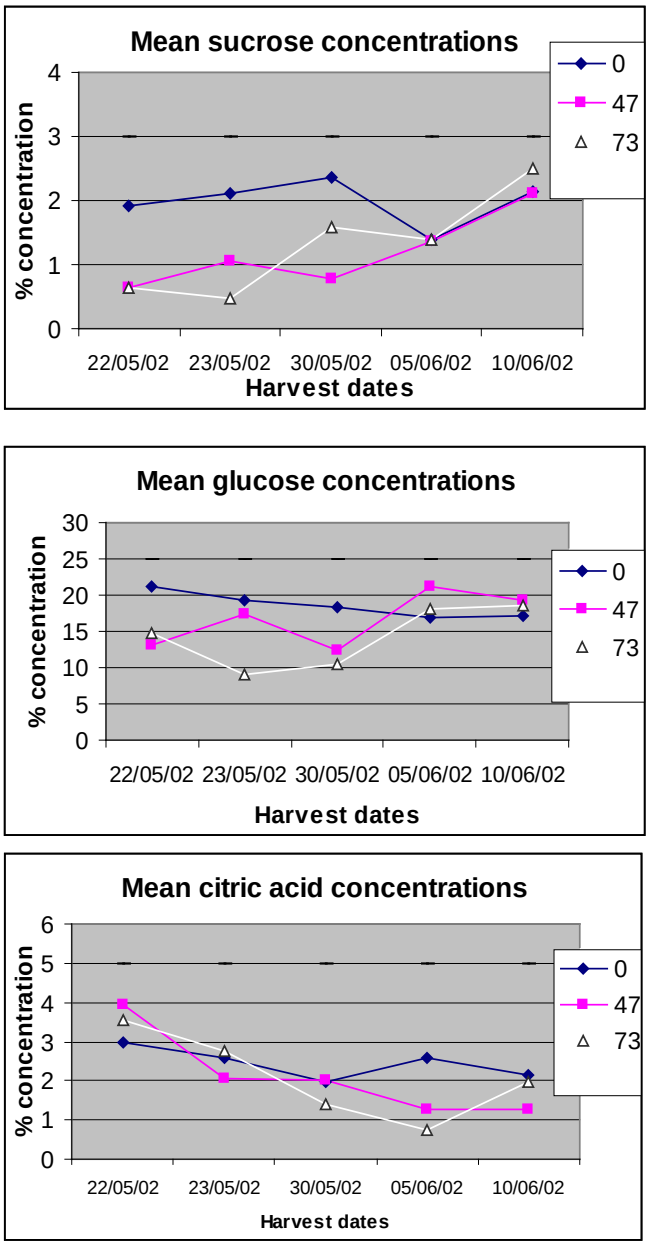


Figure 37 The influence of shading on selected non volatile flavour compounds in 'Elsanta'.

- The hedonistic taste panel (Figure 38) carried out at the first harvest found no significant differences. However the trained taste panel at the third harvest found that the control was significantly sweeter and less acidic than the 47% shade. In addition the control was found to have significantly more strawberry flavour than the 73% shade. At the forth harvest no significant differences were apparent (Table 2).

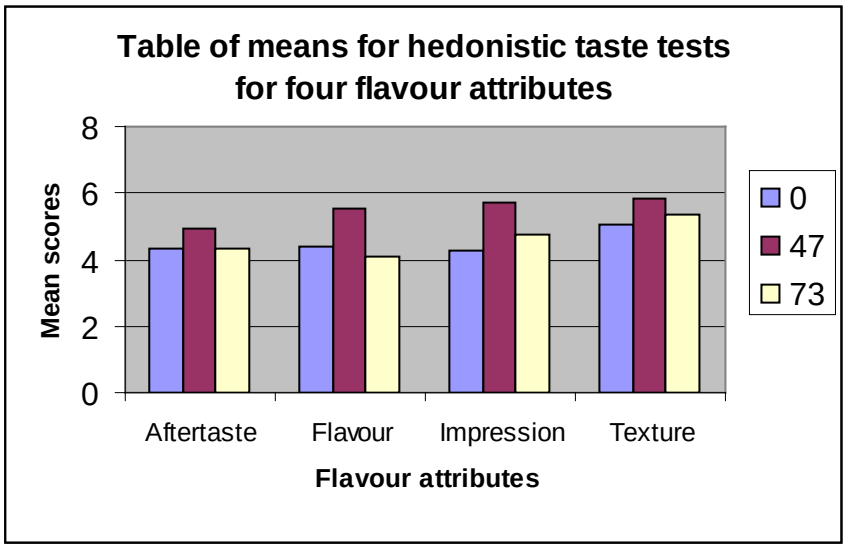


Figure 38. **The influence of plant shading on four strawberry flavour attributes Derived from the sample means tasted by 12 people, where seven was the maximum available score and one the lowest. Tested on 22/05/02.**

Table 2. The influence of Plant shading on strawberry flavour as assessed by a trained taste panel on 30 May and 6 June 2002. For this rank data 1 = the highest level of that attribute and 3 the lowest.

		Assessment on 30 May			**Assessment on 6 June**		
Attributes		**0%**	**47%**	**73%**	**0%**	**47%**	**73%**
Sweetness	Sum of ranks	19	35	30	26	16	24
	Groups	B	A	AB	n.s	n.s	n.s
Acidity	Sum of ranks	37	21	26	25	22	19
	Groups	A	B	AB	n.s	n.s	n.s
Strawberry flavour	Sum of ranks	20	29	35	19	24	23
	Groups	B	AB	A	n.s	n.s	n.s
Green (unripe flavour)	Sum of ranks	33	25	26	16	27	23
	groups	n.s	n.s	n.s	n.s	n.s	n.s

Discussion

- The influence of shading on total yield was small however this might be expected as the shading was only applied for a short period during first fruit ripening.

- Shading had some influence on volatile compounds although it was small. However it did have a noticeable effect on fruit sugars. These differences were observed at the first three harvests, by the forth harvest these differences had disappeared. This is reasonable since the shading was removed on 24 May so early developing fruit might be expected to be influenced by this shading while later ripening fruit will have developed under similar irradiance conditions.

- Unlike experiment one there was little change in sucrose levels under the 0% shading throughout the harvest period despite a significant increase in total yield over time.

- Despite the fact that there were significant differences in sugar levels at the first harvest the hedonistic taste panel could not perceive any difference in flavour. The trained taste panel could detect differences in flavour at the third harvest when there were still differences in sugar levels but could not detect differences at the forth harvest when these differences had disappeared.

Experiment 3. The effects of Fruit shading on fruit flavour compounds

This experiment reports work from the amended task 1.10 (see annual report year 3) since earlier work had shown that water stress had little impact on the development of flavour compounds. The experiment was designed to test the hypothesis that solar irradiation levels incident on the ripening fruits would affect flavour compound development.

Materials and methods

Plant growth conditions

The experiment was carried out on a commercial holding, Haygrove Farms. Single crown 'Elsanta' were planted in July 2001 in commercial peat bags in a glasshouse. The plants cropped in the autumn and used for this experiment during the second crop in spring 2002. All aspects of crop production followed the normal commercial practise for Haygrove Farms. Commercial harvest commenced on 03/05/02 and finished on 03/06/02. Fruit yield was recorded at each harvest and fruit graded into class one or class two.

Experimental treatments

Three shade treatments were applied 0%, 25% and 75%. They were replicated three times. Each plot consisted of 30 bags with 12 plants per meter planted in a double row. The shading was applied on 19/04/02 and removed on 30/04/02. The netting was supported on wires so that the

foliage canopy was not shaded but the developing fruit hanging down at the side of the bags was shaded.

Flavour analysis

Chemical flavour analysis was carried out from three harvests 09/05/02, 15/05/02 and 22/05/02. Eight fruits of a similar size and ripeness were used per plot. In addition to chemical analysis thirty fruits per treatment were sent to Marks and Spencer and to Tesco for a hedonistic taste panel.

Results and Discussion

Yield

- There was no influence of treatments on yield.

Flavour analysis

- Shading had no influence on the levels of volatile compounds. However as seen in previous experiments there were significant effects of harvest date.

- Non volatile compounds showed no significant effects of shading but again there were differences caused by harvest date.

- No significant differences due to shading were recorded by the two supermarket taste panels.

Discussion

- It would appear that the level of incident radiation on the developing fruits has no influence on flavour development. Observations in the commercial trial suggest that the rate of fruit ripening may be influenced since it was seen that fruit on the south side of a row ripens more quickly than that on the north, which is presumably a temperature effect. However ripe fruit harvested on the same day showed no differences in chemical composition or taste.

Conclusions

In both source manipulation experiments shading resulted in a loss of yield. In the fist experiment this was up to 30% in 'Elsanta' which is surprising considering the relatively short shade period to which the plants were exposed. The loss was much smaller in 'Everest' however the total yield was lower in this cultivar due to its everbearing nature. Smaller yield loss was found in the second experiment. The yield loss can be explained by the reduced supply of assimilate to the fruit due to a reduction of photosynthesis of the shaded plants.

Apart from the loss of yield observed from the shaded plants, the data also suggests that light has effects on strawberry flavour compounds. In both years shading caused a reduction in concentration of volatiles Furthermore, shade treatments resulted in a reduction of sucrose and glucose/fructose.

Importantly, it can be seen from this experiment that a relatively short period of low light had a significant effect on the flavour quality of the strawberry fruit. This has implications for growers in that a moderately brief duration of overcast weather during fruit ripening may have a significant influence on the flavour quality of their crop. The apparent sensitivity of strawberry flavour to light environment could explain the poor taste sometimes encountered in autumn-grown crops. Other workers have shown that the timing and duration of the shading period also

plays an important part in influencing flavour quality of other fruit crops (Garriz *et al* 1998, Marini *et al* 1991).

Direct shading of the fruit may also play a role in the differences in flavour compounds described above. To investigate this further experiment 3 was carried out where developing fruit alone was shaded and the plant canopy remained in full incident light. The result of this experiment showed that fruit shading alone had no impact on fruit flavour compounds suggesting that the important driving mechanism for flavour development is photosynthesis. Shading will reduce the amount of primary metabolic compounds which will lead directly to reduction in fruit sugars and in turn will mean fewer raw materials are available for acid and volatile synthesis.

All the experiments showed that there was a large amount of variation in flavour quality between fruits at any pick and also variation from harvest to harvest. Fruit-to-fruit variation can be explained due to there being fruit at different stages of maturity and ripeness within any pick. It is also probable that a sample of strawberries from a pick will be made up of a mixture of several cohorts' e.g. secondary, tertiary and quaternary fruit that may differ in their flavour make-up. In the reported experiments procedures were adopted to minimise this source of variation by using fruit of a similar size and assessing fruit ripeness using commercial fruit colour standards. Variation from harvest to harvest is, however, more difficult to clarify. It has been shown in this paper that light influences strawberry flavour compounds. The light environment experienced by the crop is likely to vary widely from harvest to harvest. By plotting light integral measured in the first experiment along with sucrose concentration measured in the 0% shading 'Elsanta' treatment suggests a good relationship between sucrose and light (interim report year 3).

Other factors will also exert their affect on flavour. As discussed above, a reduction in light could be expected to reduce plant photosynthetic rates which would in turn lead to fewer sugars available for translocation to individual fruits. Fruit sink strength could also be expected to influence carbohydrate allocation. Fruit load will increase over time meaning that even at similar light levels the amount of assimilates available to individual fruits will change throughout the harvest period. This appeared to be the case in experiment one; however no such relationship

was observed in experiment two. The greatest demand for assimilates will occur during the development of secondary and tertiary fruits.

It is important to consider what the shade-related changes in volatile and non-volatile compounds observed in this experiment actually mean in terms of human perception. Perception of flavour quality. Taste panels were carried out in all three experiments. In the fruit shading experiment no effects of treatment were found but equally there was no significant change in fruit chemical composition. In the first source manipulation experiment the hedonistic taste panel could not distinguish between treatments and the same was true for the first taste panel used in the second experiment despite measured differences in flavour compounds. Where a trained panel was used however differences could be detected in 'sweetness' 'acidity' and in one case in 'strawberry flavour'. Reduction in sugars may reduce palatability to consumers although this is an oversimplification off flavour perception. Studies have shown that there is often a synergy between flavour compounds that affect flavour perception. For example aroma and acid concentrations influence the perception of sweetness in tomato (Malundo *et al* 1995) and sugar seems to play a very important part in the perception of some volatiles as evidenced by the perception of menthone in mint chewing gum (Davidson *et al* 1999).

The results show that strawberry fruit quality s measured by the production of fruit flavour compounds is influenced by resource partitioning. A reduction in incident radiation can reduce flavour. These effects are seen after relatively short periods of low incident light experienced during berry development. Such differences can be measured and were capable of being detected by a trained taste panel. The influence of fruit load was less clear although in one experiment there was evidence that increasing fruit load lead to decreasing flavour compounds.

OBJECTIVE 3

Identify the Best Option from Available Growing Media for Fruit Production over the Extended Season

Introduction

Soil-less strawberry production systems have traditionally used peat as the substrate, with the plants grown in bags linked to a dripper irrigation system that supplies liquid feed at every watering. The number of watering cycles per day and the strength of feed applied can be varied according to the crop stage and weather conditions. These systems are designed to irrigate to approximately 20% run-off to compensate for variations in moisture content between bags, so a free-draining substrate is essential. Coarse-grade peat is typically used, with additions of lime and base fertiliser to achieve a satisfactory initial pH and nutrient status. Strawberries are susceptible to root damage if the electrical conductivity of the substrate (related to the concentration of salts) is excessive. Therefore, the conductivity of the run-off from the bags is monitored at regular intervals and adjustments made to the number of irrigation cycles and feed strength accordingly.

There has been pressure from environmental lobbyists over the last 20 years for the horticultural industry to use alternative substrates to peat, because of the concern over destruction of rare peatland ecosystems, both in the UK and elsewhere. Peat is not regarded as a sustainable material to use as a horticultural substrate. The UK government has introduced biodiversity targets related to protection of certain types of habitat such as lowland raised bogs. There are targets for 40% of all horticultural use of soil improvers and growing media to be composed of non-peat materials by 2005, and 90% replacement of peat by 2010. The first target is likely to be met, mainly by the use of other materials, such as bark, for soil improvement and mulching. The 90% target will be more difficult to meet. Multiple Retailers are starting to put pressure on their suppliers to reduce peat use as part of their environmental policies and ‘reduced peat’ substrates

have been used more widely in recent years in the ornamental horticulture sector. This trend is likely to continue.

The tasks in Objective 3 were designed to develop and evaluate novel growing methods for strawberries in bags. The overall project aims were to develop sustainable systems for non-soil strawberry culture and this part of the project focussed on the evaluation of growing media that are manufactured from renewable resources. The objective was not to develop a completely new horticultural substrate, but materials that have been successfully used in ornamental horticulture were considered to have potential for use in strawberry production and some of these were investigated.

Non-peat substrates used in experiments under Objective 3 included coir, bark, loam and green compost.

Coir

Coir or coconut fibre dust is a by-product of the coconut fibre industry. Coconut husks are traditionally soaked in water to remove the fibres. The long fibres are used for matting etc. and the short fibres and dust have been used for many years in growing media. Coir has useful characteristics such as a low bulk density, moderate pH and low nutrient status. It also has a high air capacity and is excellent for encouraging root growth, hence it is widely used in substrates for propagation. Coir must be sourced from reliable suppliers as it can contain contaminants such as salt (where it is produced in coastal areas) and human pathogens (where lagoons used for the soaking process are contaminated). Coir is regarded by some as being less environmentally friendly than other, indigenous, by-products. It is used widely in The Netherlands in horticultural substrates, including grow bags for strawberries and is a useful diluant for materials with higher bulk density and nutrient status, such as green compost.

Bark

Bark is a well-researched component of growing media for ornamental crops, pine bark being known to be superior to other bark types because it has lower levels of phytotoxic compounds.

Spruce bark is also used and was the bark type used in the Westland peat-free substrates. Deciduous barks are not generally used in growing media. The bark must be well composted or 'matured' before used to reduce nitrogen immobilisation and concentrations of phytotoxins. Bark and forestry wastes generally have a low pH, low nutrient status and good drainage so are well suited to strawberry production systems with high-volume applications of feed and water. Barks are very free-draining materials and therefore 10% of either loam (sterilised topsoil) or composted green waste was added to the Westland bark substrates to aid water and nutrient retention.

Loam

'Loam' was traditionally made for use in 'John Innes' growing media by composting stacked turves from grassland and so it had a high organic matter content. Most loam used in growing media today is sterilised topsoil, often from building/highway works. The use of loam stripped from agricultural land would not be considered sustainable. Loam provides useful water retention due to the silt and clay content and the clay particles also impart chemical buffering by holding and releasing nutrients from their surfaces. The disadvantage of loam is its weight (bulk density) which usually precludes the use of more than 10-20% in a growing medium.

Green Compost

'Green compost' (composted green waste from amenity horticulture activities) is available in large quantities due to government incentives for green wastes to be composted rather than disposed of as land-fill. This type of material is likely to be competitively priced and is also arguably the most environmentally friendly material of those available, being a true recycled product. There are concerns, however, about the consistency of the material, related to the feedstocks composted, and possible contamination risks. It is unlikely that green compost produced by every composting operation will be of high enough quality for use in horticultural growing media, but some operators are investing to produce better quality products for this market. The Waste and Resources Action Programme (WRAP) are currently developing a standard for green compost that can be used in growing media. Composted green waste is too high in nutrients to be used as 100% of the mix so it needs to be diluted with a low nutrient

material, such as coir, timber industry by-products or peat. Green compost has inherently high potassium levels, which may be of benefit for crops such as strawberries, but some composts have a high salt level (conductivity) which can damage plant roots, hence the need for dilution.

Seven experiments are reported under Objective 3:

1. Analysis of the properties of five growing media (peat and four peat free alternatives)
2. Pot experiment with five growing media (cvs. Everest and Elsanta).
3. Three media (peat and the best two peat-free media from earlier experiments), were compared for growing strawberry plants in bags (cv. Everest).
4. Evaluation of the same three media under commercial production conditions(cv. Elsanta).

5/6. The Fifth (cv. Everest) and sixth (cv. Elsanta) experiments investigated interactions between nitrogen nutrition and two growing media (peat and composted bark with 10% green compost).

7. The seventh experiment (cv. Everest) studied the levels of run-off and nitrogen supply in a peat-free growing medium.

Experiments 1-4 have already been reported, and are summarised, with reference to the earlier report.

OBJECTIVE 3 EXPERIMENTS

Experiment 1 Growing Media Preliminary Evaluation

Introduction

Representative samples of the candidate substrates for inclusion in a pot trial (Experiment 2 below) were analysed in order to determine their physical and chemical characteristics.

This experiment was reported in the Annual Report for Year 1.

Materials and Methods

The physical determinations carried out were analysis of compacted bulk density, air-filled porosity and particle size (by sieve analysis). Chemical analysis for water extractable levels of major and minor nutrients and pH was also undertaken.

The test substrates all had a low level of base fertiliser added by the manufacturers but no slow release or controlled release fertiliser.

The peat-free substrates selected had been used successfully in the ornamental horticulture sector but there was no trials evidence for their use for strawberries except for coir, which is used for strawberry production (mostly in Holland). Coir is considered by some to be a less acceptable peat alternative than materials derived from indigenous waste products because it has to be imported from Sri Lanka/India.

Table 3. Test substrates.

Substrate	Description	Source
Peat	Irish sphagnum peat, strawberry bag grade	Westland Horticulture
Coir	Sri Lankan Coir	Roffey Ltd
Bark/loam	90% composted spruce bark, 10% loam (sterilised)	Westland Horticulture
Sylvafibre/bark	70% 'Sylvafibre' (forestry waste), 30% pine bark	Melcourt Industries
Green compost/ Coir ('Eco-mix')	50% composted plant material, 50% coir	Eco-Composting

Results and Discussion

The peat had a satisfactory particle size analysis, although a slightly low air-filled porosity for strawberry bags. The pH and available nutrient ranges were all within acceptable ranges for strawberry bags.

The coir had a relatively high potassium and chloride level and a low available calcium level, as is typical for this material. It had a low air-filled porosity, however this measurement alone is not a guide to the drainage characteristics of a substrate as some materials, such as coir, have high internal porosity of the particles so they drain well despite being fine in texture.

The bark/loam mix had the coarsest texture and the highest air-filled porosity of all the substrates. The pH and available nutrient levels were all at acceptable levels for strawberry bags.

The Sylvafibre mix had a lower air-filled porosity than the bark mix but was broadly similar in chemical characteristics.

The composted green waste ('green compost') mix had a high initial electrical conductivity despite earlier batches tested having a conductivity of around 500 μs/cm. The pH of this mix was also higher than usually desirable for strawberries at 7.7, however a high pH in a substrate with a high chemical buffering capacity is less significant than it would be in peat. As typical for this type of material, the initial potassium level was very high and the nitrogen level was also high, both contributing to the high conductivity.

The analyses indicated that all the test substrates had potential for use in a strawberry production system, although the conductivity of the 'Eco-Mix' product was higher than desirable.

Experiment 2 Glasshouse Pot Experiment to Evaluate Substrates

Introduction

The media tested in Experiment 1 (above) were used in a glasshouse pot experiment, to assess which of the non-peat media had potential to support healthy plant growth and satisfactory fruit yields.

This experiment was reported in the Annual Report for Year 1.

Materials and Methods

The work was divided into two separate experiments, one with a June bearer cultivar, 'Elsanta', and one with an everbearer variety, 'Everest'. The same five substrates that were evaluated in Experiment 1 (above) were used for both cultivars. The strawberry plants were in peat modules and were potted into the test substrates in 2 litre plastic pots on 4 April 2000 (14 April for the Green Compost mix due to late delivery from the manufacturers).

The pots were randomised on a bench a glasshouse with set point temperature 15^{o}C. The experiment was carried out at ambient light levels and photoperiod.

Plants were watered without added nutrients for the first five weeks and then a standard Everbearer feed was applied to all substrates, pH 5.9 and conductivity 1,500 micro-siemens/cm. Watering was carried out by hand, some substrates requiring more frequent watering than others.

Every four weeks 3 pots in each treatment were selected and used for destructive analysis. The substrate was removed for chemical analysis and the plant tops taken for fresh weight, dry weight and leaf area measurement.

Once the plants commenced fruiting the fruit was picked twice weekly and the fruit number and weight recorded per plant. The Elsanta experiment was completed at the end of July, the Everest at the end of September.

Results and Discussion

Although the differences between yields with the Everest plants (Table 4) were not statistically significant the green compost substrate appeared to produce lower yields of fruit due to slower establishment, which was in turn due to the high initial conductivity of the substrate. The other non-peat substrates produced yields comparable with those from the peat control, with a suggestion that the bark/loam and coir treatments were superior, possibly due to their better drainage characteristics (differences not statistically significant however). The conductivity in the peat substrate rose during the first 8 weeks of the trial due to slumping of the structure of the peat and hence poor drainage. Fruit yields were initially low for all treatments during June but increased markedly during July, August and early September. The total nitrogen level in the substrate was significantly higher with the green compost mix during May, June and July, however by mid July this and the conductivity was at an acceptable level for strawberry plants.

The fruit yields with Elsanta (Table 5) were generally low. The plants in the green compost substrate did not establish, due to the high conductivity, hence there was no fruit yield from that treatment. The bark/loam and coir mixes appeared to produce slightly lower yields than the peat control and the Sylvafibre mix, however the differences were not statistically significant.

Table 4 Everest fruit yields.

Treatment	Mean weight of fruit (g) per plant.		
	Grade A fruit	Grade B fruit	Total fruit
Peat	318	189	507
Bark/loam	434	184	618
Coir	372	243	615
Sylvafibre	317	190	506
Green compost	327	136	463
SED (df= 25)	123.9	66.5	176.2
Least significant difference	255.2	136.9	362.9

Table 5. Elsanta fruit yields.

Treatment	Mean weight of fruit (g) per plant.		
	Grade A fruit	Grade B fruit	Total fruit
Peat	29.0	73.2	102.2
Bark/loam	7.5	59.0	66.5
Coir	22.0	43.1	65.1
Sylvafibre	18.2	92.6	110.7
Green compost	0.0	0.0	0.0
SED (df= 25)	11.31	14.51	19.96
Least significant difference	23.29	29.89	41.11

It is difficult to draw firm conclusions from the Elsanta trial, as it was a relatively short cropping period over which to evaluate the performance of the substrates.

The key findings from this pot experiment were that all the test substrates appeared to have potential as alternatives to peat-based substrates for the culture of everbearer strawberries in bags. The standard liquid feed used produced acceptable nutrient levels, once the initial high conductivity of the green compost substrate had reduced.

More fine-tuning of the different nutritional requirements of non-peat substrates compared to traditional peat mixes appeared to be necessary however and this was investigated in later phases of the project.

Experiment 3 Evaluation of Most Promising Non-Peat Substrates from Year 1 Pot Trial in Troughs/Bags

Introduction

The four non-peat mixes used in Experiment 2 (above) all showed potential although the blend with 50% green compost produced an excessive conductivity (total salts level). The Consortium

considered coir to be less sustainable than substrates based on indigenous forestry wastes. It was therefore decided that the two non-peat substrates to be supplied by Industry partner Westland Horticulture and evaluated in a bag system in year 2 would be the bark/loam mix and a bark/green compost mix (containing 10% green compost instead of the 10% loam).

This experiment was reported in the Annual Report for Year 2.

Materials and Methods

Samples of the substrates for inclusion in the experiment were analysed by the ADAS laboratories at Wolverhampton in order to determine their physical and chemical characteristics. The physical determinations carried out were analysis of compacted bulk density, air-filled porosity and particle size. Chemical analysis for water extractable levels of major and minor nutrients and pH was also undertaken.

Table 6. Test substrates.

Substrate	Description	Source
Peat	Irish sphagnum peat, strawberry bag grade	Westland Horticulture
Bark/loam	90% composted spruce bark, 10% loam (sterilised)	Westland Horticulture
Bark/green compost	90% composted spruce bark, 10% green compost	Westland Horticulture

The variety used was the everbearer 'Everest'. The young strawberry plants in peat modules were graded before planting into the test substrates in 0.5 metre 'grow-bags' (2 plants per 0.5 metre bag) on 17 April 2001.

The bags were randomised in six rows (six blocks) on three benches in a 15 metre polythene tunnel. The experiment was carried out at ambient light levels and photoperiod. In July the sides of the tunnel were replaced with wire mesh to 1 metre to aid ventilation and prevent temperatures rising too high.

Plants were watered with plain water until established and then a standard Everbearer feed was applied to all substrates, pH 5.9, conductivity 1,500 micro-siemens/cm. They were de-blossomed until 7 May. Watering was carried out four times a day with an automatic dripper system, all substrates receiving the same volumes of feed/water. During hot weather extra irrigation was applied.

Once the plants commenced fruiting the fruit was picked twice weekly (from 12 June), or as required and the fruit number and weight recorded per plant. The last harvest was carried out on 28 October and destructive sampling of the plants from one random bag per row per substrate was carried out on 29 October.

Results and Discussion

The initial analysis of the substrates (Table 7) showed that pH and available nutrient ranges for all the test substrates were within acceptable ranges for strawberry bags. The pH of both the bark-based mixes was significantly higher than that of the peat mix however this is less significant in a more highly chemically buffered substrate. The green compost mix had a higher chloride level than the other mixes however the overall salt level (conductivity) was not excessive. As typical for this type of material, the initial potassium level was also higher in the mix containing green compost. The initial bulk density of both the bark-based substrates was significantly higher than that of the peat: this may have implications for handling/transport of bags.

Table 7. Initial analysis of test substrates

	Peat	Bark/loam	Bark/ green compost
PH	5.9	6.9	7.1
Conductivity (μs/cm)	281	452	400
Bulk density (g/l)	332	537	502
Air-filled Porosity (%)	16.4	17.8	17.9
Phosphorus (P) (mg/l)	52	21	56
Potassium(K) (mg/l)	159	234	352
Magnesium (Mg) (mg/l)	32	16	7
Total nitrogen (N) (mg/l)	161	230	169
Nitrate-N (mg/l)	123	139	91
Ammonium-N (mg/l)	38	161	78
Calcium (mg/l)	61	47	37
Sodium (mg/l)	71	96	112
Chloride (mg/l)	61	121	225
Sulphate (mg/l)	47	132	45

The air-filled porosity of the bark/loam substrate was better at the end of the experiment (Table 4) than that of the bark/green compost. The bark-based media had significantly lower available nitrogen levels than the peat, probably due to immobilisation as the bark continued to decompose. Both the bark-based mixes had a higher pH than the peat substrate however no problems of iron/manganese deficiency were observed during the experiment. They also had a higher calcium status than the peat, which could be beneficial for fruit quality. The bark/green compost substrate had a higher chloride level than the others but the overall conductivity was not high enough to cause concern about root damage.

Table 8. Analysis at end of experiment

	Peat	Bark/loam	Bark/ green compost
pH	5.4	6.8	7.1
Conductivity (μs/cm)	222	320	354
Bulk density (g/l)	442	564	526
Air-filled Porosity (%)	13.5	13.3	10.7
Phosphorus (P) (mg/l)	17	4	9
Potassium(K) (mg/l)	129	216	318
Magnesium (Mg) (mg/l)	30	28	21
Total nitrogen (N) (mg/l)	40	4	4
Nitrate-N (mg/l)	37	3	3
Ammonium-N (mg/l)	3	1	1
Calcium (mg/l)	44	100	70
Sodium (mg/l)	113	152	173
Chloride (mg/l)	86	125	205
Sulphate (mg/l)	100	204	188

There were no statistically significant differences in total yields of marketable fruit between substrates. The total yields were: 887 g/plant for peat; 911 g/plant for bark/loam; and 852 g/plant for bark/green compost. With all the substrates there was a peak in fruit production between mid-August and mid-September.

The key findings from this experiment were that both the test substrates appeared to have potential as alternatives to peat substrates for the culture of strawberries in bags. The standard liquid feed used produced acceptable nutrient levels although the low nitrogen status in the bark substrates at the end of the trial indicated that a liquid feed with a higher nitrogen content might be beneficial with such substrates which immobilise nitrogen.

Experiment 4 Field Evaluation of Growing Media, cv. Elsanta

Introduction

The objective was to provide a comparison of the two peat-free media types that have been used in this project, together with a peat control, under commercial production conditions.

This experiment was reported in the Annual Report for year 4.

Materials and Methods

Dates	August 2002 to June 2003	
Location	Haygrove Fruit, Newent in Gloucestershire	
Treatments	**1. Bark/loam Mix**	90% composted spruce bark, 10% sterilised loam
	2. Bark/Green Compost Mix	90% composted spruce bark, 10% green compost
	3. Control	Irish sphagnum peat, strawberry bag grade
Replication	16	
Assessments	Yields and numbers of class 1 and class 2 fruit Moisture release curves for each treatment substrate	

Results and Discussion

Water in a soil or substrate is contained in pores of various sizes and, when fully saturated, all the pores are filled with water. As the medium drains, the pores empty progressively, largest first.

Water is retained more tenaciously as pore size decreases, needing an increasing pressure difference to remove the water and replace it with air.

Water in the compost held between tensions of 0.01 bars (called 'container capacity,' which is similar to field capacity of soils) and 15 bars (permanent wilting point) is regarded as being available to plants for growth.

The moisture release curves for each media are shown in Figure 39. The first data points (0.01 bar) indicate the water volume held at container capacity and the data points at the end of the plotted lines (15 bar) indicate the water volume held at permanent wilting point. The difference in water volume between these points is the available water. In general, container-grown plants are kept at the wet end of the moisture release curve, between container capacity and 1 bar, and usually below 0.1 bar. Inspection of the graph (Figure 39) reveals that the water volume lost in drying from container capacity to 1 bar, differs little between media (range 27.6 - 33.3%).

Although water availability was similar in the media tested, this may vary with degree of compaction, and it is possible that the yield differences reported (below) may be related to other physical characteristics of the media types. This requires further investigation.

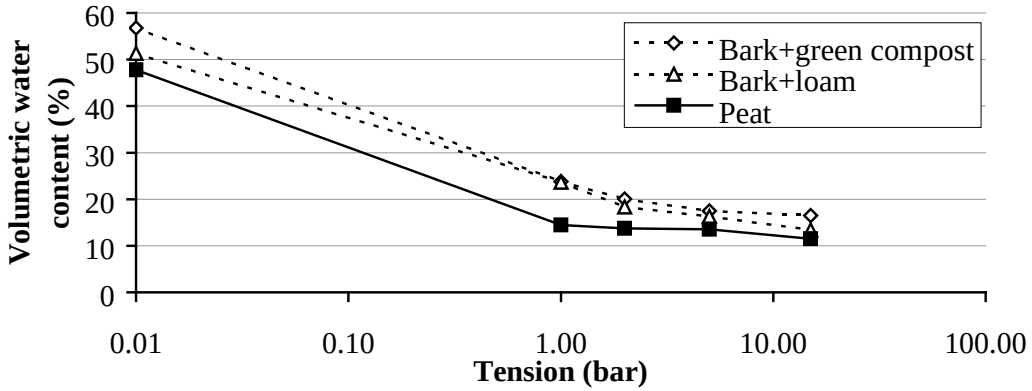


Figure 39. Moisture release curves for each of the three media.

For the autumn crop there were significant differences between media types in weight per plant of class 1 fruit (P<0.001), total weight per plant of fruit (P<0.001), number of class 1 fruit per plant (P<0.001) and total number of fruit per plant (P<0.001). Differences between growing media in weight and number of class 2 fruit per plant were small and not statistically significant. Where there were significant differences, the peat substrate performed the best and the composted bark with green compost performed least well.

For the spring crop, there were significant differences in weight of class 1 fruit (P<0.001), weight of class 2 fruit (P=0.003), total weight of fruit (P<0.001), number of class 1 fruit (P<0.001), number of class 2 fruit (P<0.001) and total number of fruit per plant (P<0.001). As with the autumn crop, the peat compost performed the best and the composted bark with green compost performed least well.

Yield results for the total of both autumn and spring crops are presented in Figures 40 and 41. The spring crop was approximately two-thirds of the total crop, and the differences between media for the total crop were similar to those for the spring crop. There were significant differences in weight of class 1 fruit (P<0.001), weight of class 2 fruit (P=0.01), total weight of fruit (P<0.001), number of class 1 fruit (P<0.001), number of class 2 fruit (P=0.007) and total number of fruit per plant (P<0.001).

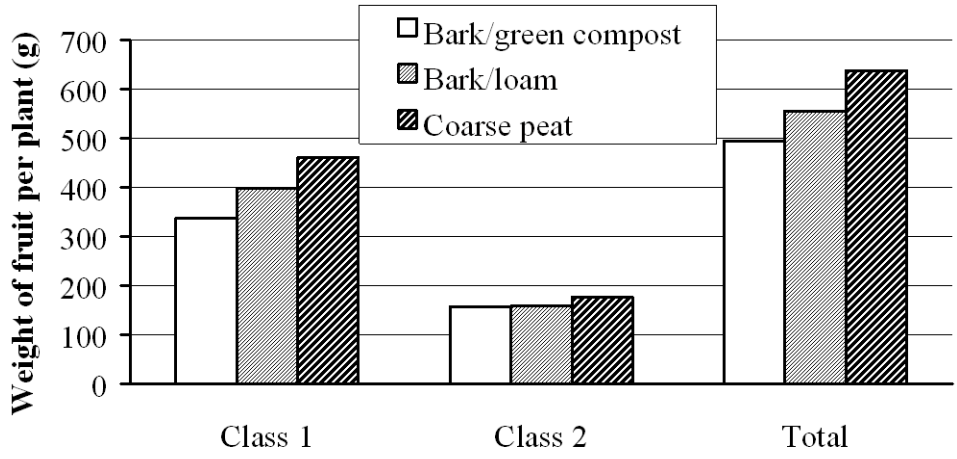


Figure 40. Average weight of fruit per plant, total of autumn and spring crops.
SEDs (28 d.f.): Class 1, 12.3; Class 2, 6.8; Total, 14.7

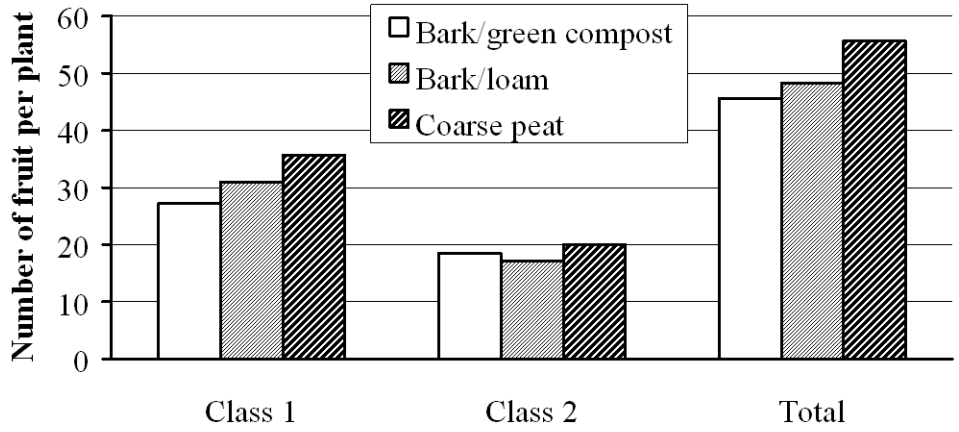


Figure 41. Average number of fruit per plant, total of autumn and spring crops.
SEDs (28 d.f.): Class 1, 1.03; Class 2, 0.79; Total, 1.40

This trial was performed under commercial conditions, with a feeding regime that was designed to be optimal for plants growing in peat compost. It is widely recognised that nutrient requirements, especially for nitrogen, differ between media. This may occur through continued breakdown of composted materials, which can decrease the availability of nitrogen to the plants, and through differences between media in leaching.

Experiment 5 Growing Media Field Evaluation, cv. Everest, and a Study of Interactions Between Media Type (peat or bark/loam) and Nutrition.

Introduction

This experiment was designed to evaluate the performance of peat-free growing media with cv. Everest, with special reference to nutritional requirements. The objectives were:

1. To compare the performance of Everest strawberry plants grown in a peat-based compost or a peat-free alternative (bark/loam).

2. To gather benchmark data (growing media and leaf analysis) for use in the further development of liquid feed programmes for the new soil-less growing system.

This experiment tested the hypothesis that the under-performance of non-peat growing media, as observed in earlier experiments with cv. Elsanta, was related to a greater requirement for nitrogen nutrition.

A progress report for this experiment was given in the Annual Report for year 4.

Materials and Methods

An experiment was performed at ADAS Arthur Rickwood using the best non-peat medium (composted bark with loam), selected from the work with Elsanta, for comparison with coarse peat.

Bark/loam mix and peat media were in bags of 1 m length. Each plot was one bag, with 4 plants, cv. Everest, per bag. There were four treatments, which were factorial combinations of two treatment factors (Table 9).

There were 4 replicates of each treatment, arranged in a randomised block design.

The experiment was performed in a polythene tunnel, 20 m × 5.8 m, covered with Luminance THB polythene (Visqueen Agri, Stockton-on-Tees, UK), but with open sides to a height of 1 m and partially open ends. Three axial fans were suspended from the centre of the tunnel to ensure ventilation when wind speed was low. The bags were supported on a steel frame 1.6 m above ground. Crop husbandry followed commercial practice for a typical crop of Everest, and included the use of bees for pollination, predatory mites for red spider mite control, and fungicide applications for mildew control.

Table 9. Treatment details for the controlled nutrition experiment.

Treatment factor	Levels	
	Treatment ID	Treatment
Media type	M1	Peat
	M2	Composted bark with loam
Nutrition	N1	Optimal for peat
	N2	Optimal for composted bark with loam

The plants were planted into the bags on 08 April 2003. The feeding programme for treatment N1 (Table 9) was designed to be typical of commercial practice for bag-grown crops. For treatment N2, the level of nitrogen was increased, but in other respects was the same as N1. Feed was delivered through dripper lines using a commercial system for supply of nutrients and water (Field (GB) Ltd, Woodchurch, UK). The number of irrigation events per day, the duration of each event and the dilution rate of the stock feed solution were varied to keep the run-off volume and electrical conductivity between pre-defined limits. For example, during fruiting, run-off volume was maintained between 10 and 25 % of the input volume and the electrical conductivity of the run-off was maintained between 1.8 and 2.0 mS. Table 10 shows typical concentrations of nutrients during the fruiting phase, assuming a dilution rate of 1:100.

For one day per week, the feeding lines were supplied from an alternative tank containing a different feed solution with a greater concentration of calcium, to ensure adequate calcium nutrition.

Yields of class 1 and class 2 fruit were assessed. The first yield assessment was on 02 June 2003 and the last yield assessment was on 01 December 2003.

Table 10. Concentrations of nutrients in feed solutions, assuming a 1:100 dilution of stock feed solution, for the fruiting phase of the crop.

		Treatment N1	Treatment N2
Nutrient			
	Ammonium-N	16 mg l^{-1}	35 mg l^{-1}
	Nitrate-N	150 mg l^{-1}	170 mg l^{-1}
	Phosphorus	46 mg l^{-1}	46 mg l^{-1}
	Potassium	300 mg l^{-1}	300 mg l^{-1}
	Calcium	83 mg l^{-1}	83 mg l^{-1}
	Magnesium	30 mg l^{-1}	30 mg l^{-1}
	Iron	1.50 mg l^{-1}	1.50 mg l^{-1}
	Manganese	0.00 mg l^{-1}	0.00 mg l^{-1}
	Copper	0.20 mg l^{-1}	0.20 mg l^{-1}
	Zinc	0.63 mg l^{-1}	0.63 mg l^{-1}
	Boron	0.12 mg l^{-1}	0.12 mg l^{-1}
	Molybdenum	0 mg l^{-1}	0 mg l^{-1}
	Chloride	51 mg l^{-1}	51 mg l^{-1}
Conductivity		1724 µS	1883 µS
Ratios	K/N	1.8	1.5
	K/Ca	3.6	3.6
	K/Mg	10	10

Results and Discussion

Growing media treatments differed significantly in total weight of fruit (total of class 1, class 2 and unsaleable, *P*=0.020) (Table 11) and in the total of class 1 and 2 (*P*=0.046) (Table 10 and Figure 42). In both cases, yield was greater in peat than in composted bark with 10% loam. Yields of saleable fruit did not differ significantly between nutrition treatments (Table 10).

Table 11. Total weight of fruit per plant, statistical significance (*P* and SEDs).

	Weight of fruit per plant (g)						
	Growing media			Nutrition treatment			
	Peat	**Bark + loam**	***P***	**N1**	**N2**	***P***	**$SED_{9\ d.f.}$**
Class 1	391.8	341.9	NS	352.1	381.6	NS	26.40
Class 2	315.7	263.5	NS	276.4	302.8	NS	28.81
Class 1 + class 2	707.5	605.4	0.046	628.5	684.4	NS	44.13
Unsaleable	208.7	152.7	0.012	160.1	201.4	0.046	17.82
Class 1 + class 2 + unsaleable	916.2	758.1	0.020	788.6	885.8	NS	56.00
Unripe fruit	64.3	48.3	NS	52.3	60.3	NS	9.42

There were no significant interactions between growing media treatments and nutrition treatments. Such an interaction would have supported the hypothesis that the under-performance of non-peat growing media, was related to a greater requirement for nitrogen nutrition, if there had been a yield response to nitrogen in the non-peat treatment, but not in the peat treatment. However, the results do not support this hypothesis, suggesting that the cause of the relatively poor performance of the non-peat growing medium was related to some other factor.

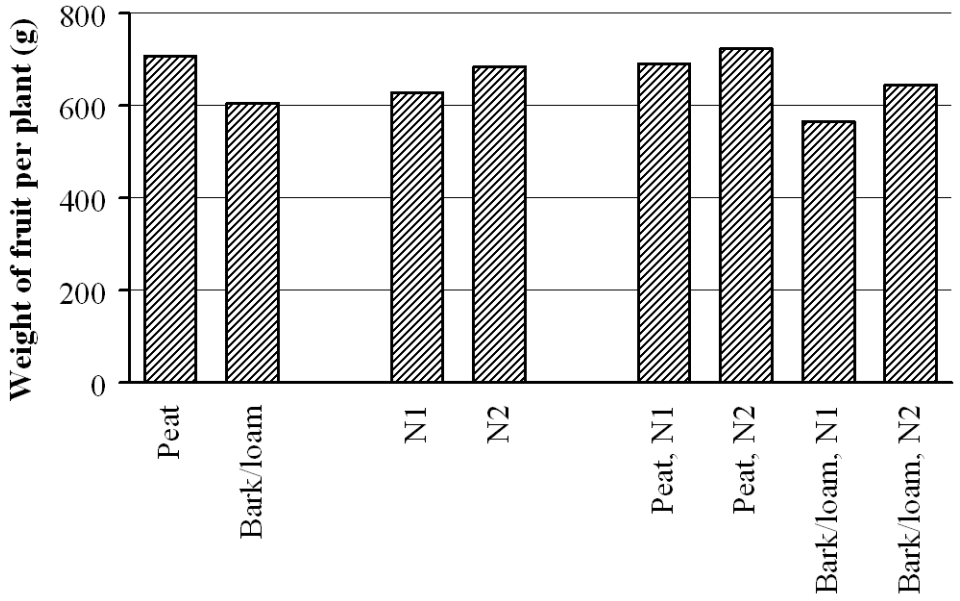


Figure 42. Average total weight of fruit per plant, Class 1 + Class 2: means for each media and nutrition treatment and treatment combinations.
SED (9 d.f.) = 44.1 for main treatments, and 62.4 for treatment combinations.

An analysis of variance was performed to test whether the trend in yield over time differed between treatments. For this purpose, yield data were totalled for each 14 day period throughout picking. This had the effect of smoothing, to some extent, the short-term fluctuations in yield, between picking occasions. The data are presented Figure 30. The data were analysed treating the experiment design as a split-plot design with treatments as whole plots and time as the subplots. With repeated measurements there was likely to be a greater correlation between observations made at adjacent times than between observations separated by greater time intervals. Furthermore the time factor may not be allocated at random to occasions within treatments. A procedure (AREPMEASURES) within GENSTAT (Payne *et al.,* 1993) was used to deal with this. A correction factor, Greenhouse-Geisser epsilon, was calculated and used to adjust the degrees of freedom in the subplot stratum. This procedure is described in detail in Greenhouse and Geisser (1959). There were no significant interactions between time and treatments, indicating that the pattern of change with time did not differ significantly between treatments.

Yield decreased sharply in late August and remained at a low level throughout September (Figure 43). This followed a period of high ambient temperature in August (Figure 44), which would be expected to induce thermo-dormancy, decreasing flower initiation.

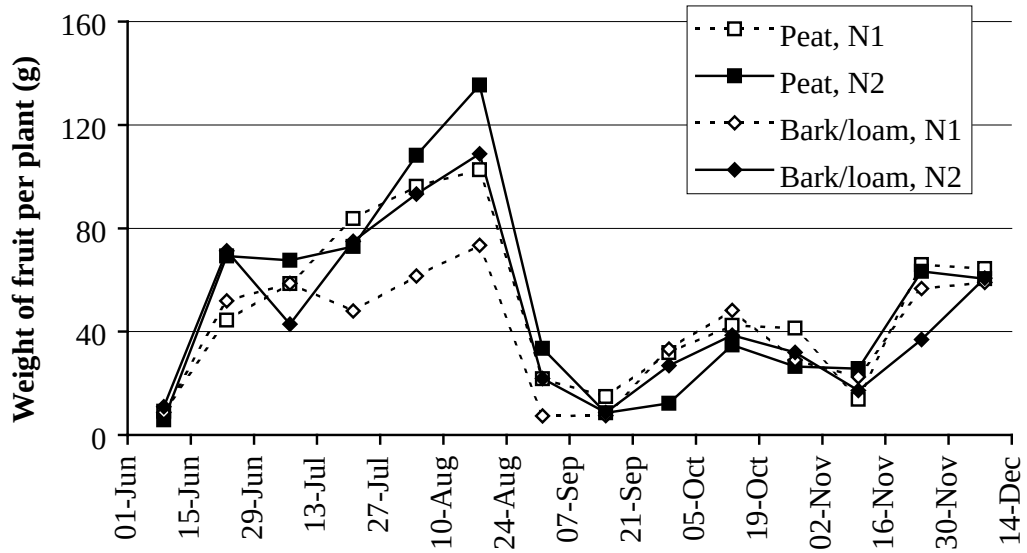


Figure 43. Mean weight of fruit per plant for each two week period throughout picking, for each treatment combination. Yield data are plotted against the eighth day of each 14 day period.

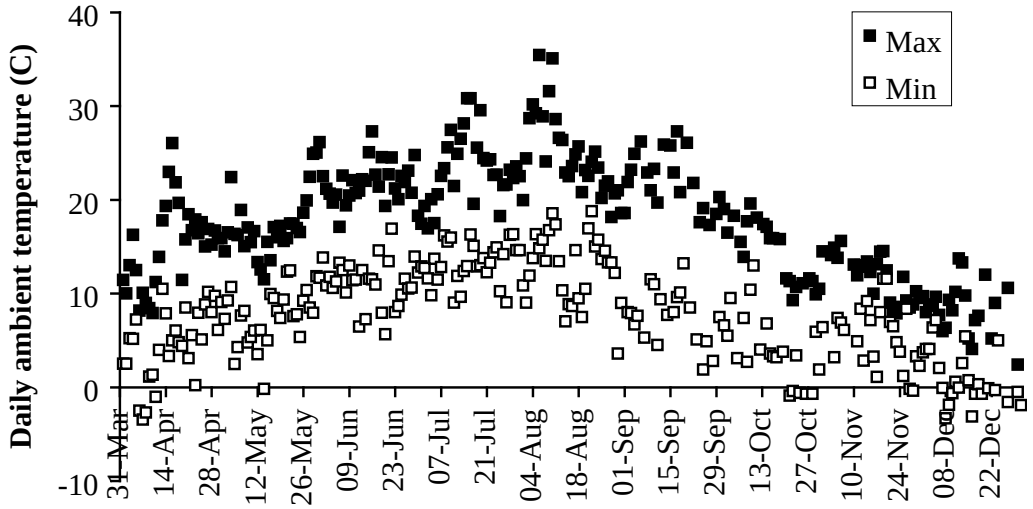


Figure 44. Maximum and minimum daily temperatures (°C) at ADAS Arthur Rickwood, April to December 2003.

Table 12. Foliar nutrient analysis on five dates (% of dry matter).

	Treatment			
Nitrogen				
	Peat, N1	**Peat, N2**	**Bark+loam. N1**	**Bark+loam, N2**
16 Jun	2.65	2.75	2.37	2.51
11 Aug	2.30	2.32	2.21	2.22
16 Sep	2.67	2.71	2.76	2.83
22 Oct	2.75	2.81	2.74	2.79
01 Dec	2.55	2.75	2.70	2.76
Calcium				
	Peat, N1	**Peat, N2**	**Bark+loam. N1**	**Bark+loam, N2**
16 Jun	1.56	1.82	1.46	1.72
11 Aug	1.14	1.15	1.19	1.13
16 Sep	1.37	1.22	0.79	0.79
22 Oct	0.83	0.91	0.97	0.60
01 Dec	1.14	1.17	1.20	1.19
Potassium				
	Peat, N1	**Peat, N2**	**Bark+loam. N1**	**Bark+loam, N2**
16 Jun	2.09	2.19	2.23	2.13
11 Aug	2.07	2.39	2.44	2.52
16 Sep	1.52	1.86	2.73	2.73
22 Oct	2.22	2.48	2.37	1.49
01 Dec	2.39	2.36	2.39	2.53
Magnesium				
	Peat, N1	**Peat, N2**	**Bark+loam. N1**	**Bark+loam, N2**
16 Jun	0.37	0.36	0.30	0.32
11 Aug	0.41	0.38	0.46	0.41
16 Sep	0.15	0.18	0.22	0.23
22 Oct	0.21	0.25	0.25	0.18
01 Dec	0.23	0.24	0.24	0.25
Phosphorus				
	Peat, N1	**Peat, N2**	**Bark+loam. N1**	**Bark+loam, N2**
16 Jun	0.41	0.37	0.34	0.36
11 Aug	0.38	0.39	0.38	0.39
16 Sep	0.32	0.37	0.47	0.50
22 Oct	0.46	0.58	0.55	0.38
01 Dec	0.47	0.52	0.57	0.61

Results of foliar nutrient analysis on five dates (Table 12) did not indicate any nutrient deficiencies in any treatment. The substrate analysis (Table 13) showed that the peat had the lowest pH, conductivity and density. There were also differences between peat and non-peat media in the content of several nutrients (Table 13), although none of these differences had any detectable effect on foliar nutrient content. Notably, mineral nitrogen content was lower in the non-peat medium. Phosphorus and potassium were also higher in the peat medium, whereas calcium, sulphate, chloride and iron were all lower.

Table 13. Substrate nutrient analysis after the end of picking, statistical significance (*P* and SEDs).

	Growing media nutrient analysis						
	Growing media			**Nutrition treatment**			
	Peat	**Bark + loam**	***P***	**N1**	**N2**	***P***	**$SED_{9\ d.f.}$**
pH	6.325	7.088	<.001	6.775	6.637	NS	0.0809
Conductivity (µSC)	260	389	0.008	308	341	NS	37.8
Density (g/l)	559.9	585.4	0.030	585.7	559.5	0.026	9.88
Phosphorus (mg/l)	39.2	9.4	<.001	27.6	21.0	NS	3.18
Potassium (mg/l)	253.9	334.9	0.001	310.4	278.4	NS	17.65
Magnesium (mg/l)	27.0	38.7	NS	27.5	38.2	NS	7.35
Mineral N (mg/l)	95.2	40.7	0.001	65.1	70.9	NS	11.43
Calcium (mg/l)	55	144	0.002	83	116	NS	20.5
Sodium (mg/l)	60.9	82.1	NS	65.9	77.1	NS	10.54
Chloride (mg/l)	55.2	81.5	0.048	64.2	72.5	NS	11.45
Sulphate (mg/l)	58	232	<.001	128	162	NS	26.4
Boron (mg/l)	0.315	0.225	NS	0.320	0.220	NS	0.0758
Iron (mg/l)	0.38	2.99	<.001	1.84	1.53	NS	0.404

Experiment 6 Comparison of Commercial Performance of Peat-based Compost and Bark/loam Mix (cv. Elsanta).

Introduction

Earlier results (Experiment 4) showed that, for cv. Elsanta, if the nutrition was optimised for peat, then the peat performed better. The original work plan was changed to allow the inclusion of nutrition treatments in this experiment, to test the hypothesis that the under-performance of peat-free media was related to a requirement for increased nitrogen nutrition. The main change to the earlier work plan was the addition of two treatments using a bark/loam mix, with additional slow-release N added to the bags at planting.

Materials and Methods

The performances of two types of growing media were compared under commercial conditions at Haygrove Fruit, Newent in Gloucestershire.

The two types of media used were:

1. Bark/loam Mix 90% composted spruce bark, 10% sterilised loam
2. Control Irish sphagnum peat, strawberry bag grade

There were four treatments:

M1	Peat
M2N0	Composted bark with loam, no slow-release N
M2N1	Composted bark with loam, 0.5 g/l slow-release N
M2N2	Composted bark with loam, 1 g/l slow-release N

The slow release N was applied as Multicote 4 (40:0:0).

Each plot was 0.5 m long, with 6 plants, cv. Elsanta, per plot, planted in a double row. There were eight replicates of each treatment, arranged in a randomised block design.

Cold-stored plants were planted into the bags on 28 July 2003, with a view to taking an autumn crop. The experiment was in a large glasshouse planted with the same cultivar. All aspects of crop maintenance followed the commercial practice for the Haygrove Fruit site.

Yields of class 1 and class 2 fruit were assessed. The first yield assessment was on 29 September 2003 and the last yield assessment was on 09 December 2003.

Results and Discussion

There was a significant effect of treatments on Class 1 yield (Table 14): Yield for treatment M1 (peat) was greater than for the other treatments. There were no significant effects of treatments on yields of class 2 or unsaleable fruit. The differences in yields of class 1 fruit resulted in significant differences in total yields, with greatest yield in the peat treatment.

Differences between treatments in numbers of fruit per plant (Table 14) were similar to the differences in yields.

Table 14. Total weight of fruit per plant and statistical significance (*P* and SEDs).

	Weight of fruit per plant (g)					
	M1	**M2N0**	**M2N1**	**M2N2**	**$SED_{21\ d.f.}$**	***P***
Class 1	72.9	49.9	38.7	42.4	5.50	<.001
Class 2	40.7	43.1	40.6	37.4	4.82	NS
Class 1+class 2	113.6	92.9	79.2	79.8	8.22	0.001
Unsaleable	60.9	59.9	63.7	61.0	7.14	NS
Class 1 + class 2 + unsaleable	174.5	152.9	143.0	140.8	11.80	0.036

Table 15. Total number of fruit per plant and statistical significance (*P* and SEDs).

	Number of fruit per plant (g)					
	M1	**M2N0**	**M2N1**	**M2N2**	**$SED_{21\ d.f.}$**	***P***
Class 1	5.9	4.1	3.2	3.7	0.46	<.001
Class 2	4.3	4.5	4.2	4.1	0.50	NS
Class 1+class 2	10.2	8.6	7.4	7.8	0.76	0.008
Unsaleable	8.6	9.9	10.1	9.1	1.15	NS
Class 1 + class 2 + unsaleable	18.8	18.6	17.5	16.9	1.52	NS

The weight of fruit per plant on each picking occasion is shown in Figure 45. An analysis of variance was performed to test whether the trend in yield over time differed between treatments. The data were analysed treating the experiment design as a split-plot design with treatments as whole plots and time as the subplots. With repeated measurements there was likely to be a greater correlation between observations made at adjacent times than between observations separated by greater time intervals. Furthermore the time factor may not be allocated at random to occasions within treatments. A procedure (AREPMEASURES) within GENSTAT (Payne *et al.*, 1993) was used to deal with this. A correction factor, Greenhouse-Geisser epsilon, was calculated and used to adjust the degrees of freedom in the subplot stratum. This procedure is described in detail in Greenhouse and Geisser (1959). There were no significant interactions between time and treatments, indicating that the pattern of change with time did not differ significantly between treatments.

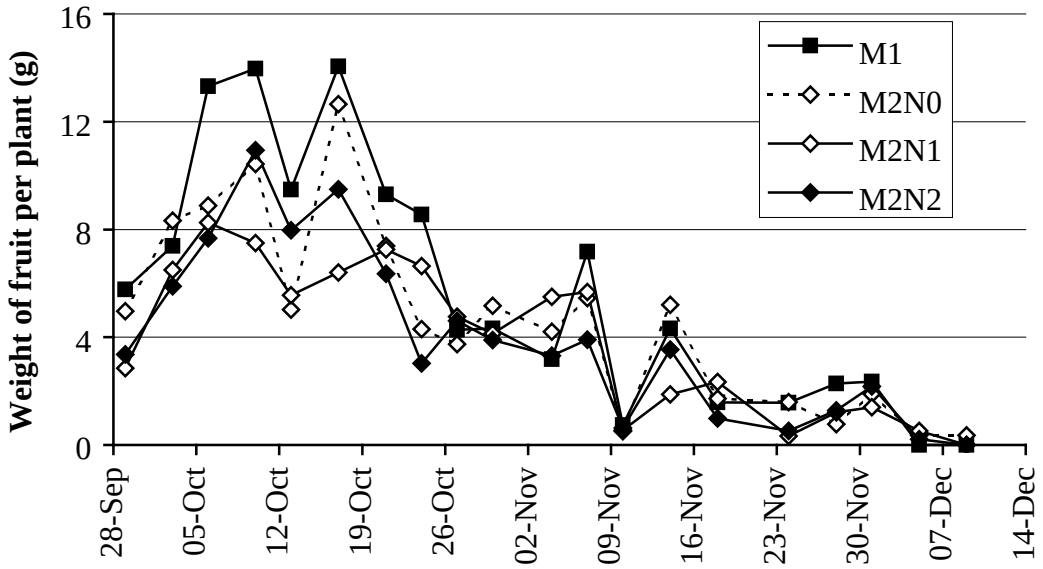


Figure 45. Mean weight of fruit per plant (g) for each picking occasion, for each treatment.

The differences in yield between the peat treatment and the other (non-peat) treatments occurred mainly during the month of October (Figure 45), after which, yields declined and differences between treatments were less consistent.

In the three non-peat treatments, there was no clear response of fruit yield or number to additional nitrogen (Tables 13 and 14). Differences between these treatments were small, but the greatest yield was in the treatment with no slow-release nitrogen. These results suggest that nitrogen was not limiting yield in the non-peat treatments. It is not apparent what factors are causing the differences in yield between the peat and non-peat media.

Results of foliar nutrient analysis on three dates (Table 16) did not indicate any nutrient deficiencies in any treatment. Foliar nitrogen contents were similar at the end of picking.

Table 16. Foliar nutrient analysis on three dates.

	Treatment			
Nitrogen (% dry matter)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	3.03	3.06	2.98	2.95
24 Nov	2.78	2.78	3.04	3.18
09 Dec	2.68	2.58	2.63	2.45
Calcium (% dry matter)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	1.67	1.81	1.79	1.49
24 Nov	1.68	1.47	1.22	1.34
09 Dec	1.93	1.65	1.68	1.53
Potassium (% dry matter)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	2.96	2.83	2.86	2.91
24 Nov	2.59	2.64	1.86	2.51
09 Dec	2.43	2.69	2.93	2.88
Magnesium (% dry matter)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	0.51	0.50	0.51	0.43
24 Nov	0.48	0.41	0.47	0.42
09 Dec	0.56	0.42	0.42	0.38
Phosphorus (% dry matter)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	0.60	0.53	0.47	0.52
24 Nov	0.51	0.45	0.54	0.49
09 Dec	0.61	0.49	0.47	0.47
Sulphur (% dry matter)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	0.17	0.16	0.17	0.19
24 Nov	0.18	0.22	0.31	0.25
09 Dec	0.18	0.17	0.17	0.15

Table 16 (continued). Foliar nutrient analysis on three dates.

	Treatment			
Sodium (% dry matter)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	0.03	0.03	0.05	0.04
24 Nov	0.05	0.07	0.17	0.11
09 Dec	0.08	0.05	0.06	0.04
Boron (mg/kg)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	74.5	81.1	79.9	82.8
24 Nov	68.0	60.3	43.6	51.7
09 Dec	83.0	76.2	76.3	74.2
Iron (mg/kg)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	254	199	236	234
24 Nov	318	301	342	291
09 Dec	471	324	330	356
Zinc (mg/kg)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	32.2	32.0	42.7	39.0
24 Nov	45.4	61.6	111	75.6
09 Dec	61.1	46.0	43.0	43.3
Manganese (mg/kg)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	198	126	108	163
24 Nov	191	87.8	166	125
09 Dec	247	117	105	185
Copper (mg/kg)				
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
21 Oct	4.88	5.03	5.77	5.65
24 Nov	19.2	14.0	29.9	19.3
09 Dec	12.3	7.42	6.26	5.72

Substrate nutrient analysis after the end of picking (Table 17) showed that the peat had the lowest pH, conductivity and density. Greater foliar manganese content in the peat treatment (Table 15) is indicative of the lower pH in the medium. Treatments with added slow-release N had higher levels of mineral nitrogen, showing that the slow-release product was not exhausted at the end of picking. Levels of calcium, chloride, sulphate, boron, zinc and iron were all lower in peat than in the non-peat alternative.

Table 17 Substrate nutrient analysis after the end of picking.

	Substrate nutrient analysis			
	Peat	**Bark+loam, N0**	**Bark+loam, N1**	**Bark+loam, N2**
pH	5.7	6.8	6.2	6.2
Conductivity (μSC)	133	182	316	289
Density (g/l)	476	615	603	664
Phosphorus (mg/l)	12	12	14	15
Potassium (mg/l)	107	177	210	211
Magnesium (mg/l)	21	22	56	47
Mineral N (mg/l)	70	66	155	132
Calcium (mg/l)	43	63	158	132
Sodium (mg/l)	18	26	30	28
Chloride (mg/l)	22	34	37	34
Sulphate (mg/l)	19	54	91	89
Boron (mg/l)	<0.10	0.25	0.23	0.27
Copper (mg/l)	<0.15	<0.15	<0.15	<0.15
Manganese (mg/l)	<0.1	<0.1	0.1	0.2
Zinc (mg/l)	<0.10	0.23	0.24	0.22
Iron (mg/l)	1.03	5.30	3.04	3.45

Experiment 7 **a) Reducing the Volume of Fertigation Run-off from Bag-Grown Strawberry**

b) Enhancing Substrate Nutrition to Ensure Adequate Nitrogen Supply

Introduction

The aims of the work were to carry out an evaluation of the potential to reduce fertigation run-off and ensure adequate nitrogen nutrition using everbearers (cv. Everest) grown in the ADAS-recommended growing media (bark/loam, 90/10 v/v) mix. Commercially fertigation/irrigation is nominally supplied at around an input volume that allows for 20% wastage. Run-off at this level is believed to ensure that the plants are adequately supplied with water and crop yield and quality are not nutritionally limited. However, this level of water wastage can have important implications for production costs and environmental impact. Such costs and impacts are likely to influence the sustainability of strawberry production even more in the future. Equally important in the delivery of a novel strawberry growing system are concerns that compost media, with a high bark content, may provide insufficient nutrition, particularly nitrogen, to meet the plant's demand. These two objectives have been evaluated experimentally by reducing the irrigation inputs to different levels, while quantitatively monitoring run-off, cropping and crop quality. Adequate nutrition was ensured, particularly with respect to nitrogen application, by supplementation of a standard commercial 'Agrosol F316' regime. In previous experiments, the standard 'Agrosol F316' regime had been tried and tested at East Malling using the cultivar Everest. So this it was considered the most appropriate for further use in these experiments. This choice was strongly influenced by high cropping levels and fruit quality previously obtained with this product. The continued use of 'Everest' in these experiments also ensured that there were no confounding problems associated with changing more than one variable at a time within an experiment.

Material and Methods

Experiment 7a: Reducing the Volume of Fertigation Run-off from Bag-grown Strawberry.

Experimental Aim:

Determine how fertigation/irrigation run-off can be reduced without compromising fruit yield and quality of bag-grown Everest in a bark/loam compost mix.

Experimental Protocol:

Cultivar:	Everest
Plant type:	Bare rooted
Substrate:	Bark loam mix (90/10)
Container:	Large bags 5 plants
Date of planting:	May
Location:	Polytunnel
Treatments:	4 levels of run off (5, 10, 15 and 20%)
Replication:	6 bags (2 bags per table)
Fertigation:	Agrosol F316
Duration:	5 months

Measurements:

Routine monitoring of run-off volume

Routine monitoring of EC in run-off

Routine monitoring of EC in bags

Fruit number, weight and class.

Leaf mineral analysis (macro- and micro-nutrients at mid season). Analysed by HRI Wellesbourne.

Substrate analysis (at end of experiment). Analysed by HRI Wellesbourne

Experiment 7b: Enhancing Substrate Nutrition to Ensure Adequate Nitrogen Supply.

Experimental Aim:

Determine the benefits of supplementary fertigation (nitrogen nutrition) on bag-grown Everest in a bark loam compost mix.

Experimental Protocol:

Cultivar:	Everest
Plant type:	bare rooted
Substrate:	Bark loam mix (90/10)
Container:	Large bags 5 plants
Date of planting:	May
Location:	Polytunnel
Treatments:	2 nutrient regimes (standard 'Agrosol F316' at 1 kg to 10 litres of water and 'Agrosol F316 at 1.25 kg to 10 litres of water)
Replication:	6 bags (2 bags per table)
Duration:	5 months
Measurements:	Routine monitoring of run-off volume. Routine monitoring of EC in run-off water. Routine monitoring of EC in bags. Fruit number, weight and class. Leaf mineral analysis (macro- and micro-nutrients at mid season). Analysed by HRI-Wellesbourne. Substrate analysis (at end of experiment). Analysed by HRI-Wellesbourne.

After consultation with a biometrician a single experiment was designed to combine the run-off and nutrition aspects of the two protocols described above (experimental plan not shown here see Horticultural Link Project 215, Annual Report Year 4).

Protocol Used for the Combined Experiment

A side and top vented polytunnel was used, in which was constructed 6 rows of bag tables running north south, within each row were 5 tables (see Horticultural Link Project 215, Annual Report Year 4). Each of the separate tables within a single row held 2 bags, each bag was planted with 5 bare rooted cold stored grade A plants and each table represented an experimental analysis unit. In some cases each table (containing 2 grow bags) was used as an analysis unit for data expression and is equivalent to 10 individual plants.

To enable water (run-off) draining from the bag to be collected, quantified and various constituents measured, (primarily pH and EC) the bags were mounted on ridged polythene trunking running the length of each individual table, i.e. two bags emptying into a single drain trunking. At the end of each table a standard household plastic bucket collected the run-off. The tables had a slight north south incline to ensure the run-off, after draining from the bags, was rapidly delivered into the plastic bucket. The buckets were covered with polythene to minimise evaporation from the bucket.

Water and nutrition (fertigation) was delivered using two dosatrons, one provided the standard 'Agrosol F316 feed' (1 kg per 10 litres of water) to the plants within experiment 1 and to those bags/plants within the nutrition experiment 2 which were to act as controls (standard concentration of 'Agrosol' feed). The second dosatron fed those plants receiving the extra nutrition at a rate of 1.25 kg per 10 litres of water ('Agrosol' feed). In a preliminary investigation, it was determined that the most satisfactory way to regulate the amount of water required to achieve different amounts of run-off (5 to 20% of input) was to vary the number of drippers supplying each bag. Initial experiments also demonstrated how difficult it was to be consistent with the delivery (repetition) and actual amount of water required to achieve the desired run-off (see results section). The amount of water required varied mainly due to daily differences in plant usage. Water usage can be closely related to climatic conditions. Such usage cannot, however, be predicted and so manual adjustments have to be made frequently. Preliminary experiments also highlight the large degree of variability between water delivery rates even when using pressure compensating dripper irrigation nozzles. After sometime

attempting to achieve equal and reproducible delivery rates to bags the trickle irrigation nozzles were replaced with 'Netafim' 2 litre per hour pressure compensation drippers which stopped the back flow of air into the pipe system.

The different amounts of irrigation required to vary run-off between 5 to 20% were achieved by increasing the number of drippers per bag, as follows:
Treatment 1 = 1 dripper per bag (approximately 5% run-off)
Treatment 2 = 2 drippers per bag (approximately 10% run-off)
Treatment 3 = 3 drippers per bag (approximately 15% run-off)
Treatment 4 = 4 drippers per bag (approximately 20% run-off) control treatment

For the high nutrient treatment;
Treatment 5 = 4 drippers per bag giving a 20% run-off + extra nutrition (nitrogen)

During the season it was found that in order to achieve the desired run-off rates dripper number per bag was varied. This enabled more irrigation to be supplied when climate regimes, high light and temperature levels in particularly, induced high plant water use rates. To combat this, dripper number was varied for treatments 1 & 2 as follows:
1 = varied between 1 and 2 drippers per bag (5% run-off);
2 = varied between 2 and 3 drippers per bag (10% run-off).

The timing of the fertigation events was based on previous experience with the aim of providing irrigation when demand was generally likely to ensure optimal usage and therefore minimal wastage (run-off). Initial timing was for 5 minutes at 8:00 h each day and increased to twice per day by including an additional 5 minutes at 14:00 h. As the season became hotter, run times were changed to 3 times per day at 8:00, 12:00 and 16:00 h, and at very warm temperatures a further event per day adding another run-time at 20:00 h.

Also the length of the fertigation events was frequently manipulated to ensure that run-off was as close to the pre-set points of 5, 10, 15 and 20% of input. The need to alter the length of fertigation events was also found necessary to compensate for changes in plant growth (leaf area development and cropping), as well as those associated with daily changes climate. For example,

days when solar radiation was high along with plant water use, demanded greater fertigation input relative to days when solar radiation and temperature dictated lower plant water use. To ensure that fertigation supply rates were close to those required, the amount of run-off water was monitored throughout the experiment along with the compost media water content. Measurements of the latter were made to attempt to ensure that run-off alone varied without necessarily reducing the media bag water content detrimentally, i.e. creating drought stress (see results section). These measurements were taken at two-week intervals.

Run-off was assessed by weighing the collecting buckets and their contents twice weekly, and the amount of fertigation input was monitored (by direct collection) to determine actual percentage run-off. At the same time fertigation input and run-off water was monitored for pH and electrical conductivity (EC). Non-destructive measurements of leaf nitrogen status were taken throughout the growing season to monitor changes in leaf chlorophyll content (using a chlorophyll content meter). The photosynthetic pigment chlorophyll is the primary user of plant nitrogen and elemental nitrogen deficiency can be rapidly detected by measuring leaf fluorescence. Deficiencies in leaf nitrogen primarily impact by reducing photosynthesis, along with subsequent reductions in plant and fruit growth.

The crop was harvested and recorded twice weekly until the end of September. Also, leaf samples were taken for mineral analysis in the middle of the season and runners were removed and counted during the growing season. Fresh plant weights were taken at the end of the season and two blocks were also used for the determination of the allocation of dry matter to the above ground parts. Plant dry matter samples and those of the substrate were taken for mineral analysis and substrate pH and EC measured at the end of the season.

Results and Discussion

Monitoring Fertigation Inputs and Run-off Water

Table 18 shows the mean treatment total fertigation input expressed as a volume (litres). This data was then used to calculate the percentage run-off relative to the fertigation-input value

(Table 19). The treatment and seasonal differences in the amount of run-off achieved are shown in Figure 46. These values are derived from mean weekly amount collected and are expressed as a percentage of applied fertigation input. Statistical comparisons are shown for each sampling date (Tables 18 and 19). Figure 46 demonstrates the difficulty in maintaining a constant run-off value when water usage (uptake by the plant) varies with daily climate.

Treatment differences in run-off values determined at the end of the growing season are shown in Figure 47. These differences show that the percentage run-off generated was generally closely matched the desired experimental values, i.e. 5%, 10%, 15% and 20% of input. The only exception was the extra nutrient (treatment 5), which produced a run-off value closer to 30% rather than the desired 20%.

Table 18. Mean weekly measurements of fertigation input expressed as total number of litres applied

Week start date	5% run-off	10% run-off	15% run-off	20% run-off C	20% run-off N	SED	*f.prob*
1-Jun	1.4	2.4	2.9	4.0	4.0	0.12	<0.001
8-Jun	1.0	1.5	1.5	2.0	2.2	0.15	<0.001
15-Jun	5.3	8.4	10.3	12.5	12.7	0.32	<0.001
22-Jun	22.8	34.2	34.2	45.6	45.6		
29-Jun	24.3	36.5	36.5	48.6	48.6		
6-July	26.6	35.6	39.9	53.2	53.2	0.08	<0.001
13-Jul	31.9	39.7	47.9	63.8	63.8	1.04	<0.001
20-Jul	42. 6	57.8	63.8	85.1	85.1		
27-Jul	33.4	46.4	50.2	66.9	66.9		
3-Aug	24.3	36.5	36.5	48.6	48.6		
10-Aug	42.6	58.5	63.8	85.1	84.1	0.64	<0.001
17-Aug	42.6	61.6	63.8	85.1	83.3	1.12	<0.001
24-Aug	38.5	43.3	50.2	66.9	62.5	3.11	<0.001
31-Aug	20.5	27.6	30.8	41.0	40.2	0.54	<0.001
7-Sep	18.2	23.6	27.4	36.5	35.7	0.48	<0.001
14-Sep	15.9	23.9	23.9	31.9	31.3	0.42	<0.001
21-Sep	19.8	24.3	29.6	39.5	33.1	0.20	<0.001
28-Sep	25.8	35.3	38.8	51.7	40.2	0.54	<0.001

Table 19: Mean weekly measurements of fertigation run-off expressed as percentage of input volume

Week start date	5% run-off	10% run-off	15% run-off	20% run-off C	20% run-off N	SED	*f.prob*
1-Jun	0.87	3.80	17.78	34.14	17.00	3.50	<0.001
8-Jun	0.74	2.87	15.22	32.14	20.94	3.48	<0.001
15-Jun	4.26	7.07	18.75	35.06	26.75	3.61	<0.001
22-Jun	5.51	10.20	13.61	20.66	21.32	2.35	<0.001
29-Jun	2.17	8.85	11.90	23.05	24.59	2.73	<0.001
6-July	6.27	15.10	16.37	26.83	31.27	3.02	<0.001
13-Jul	18.96	27.59	34.87	42.38	48.45	3.39	<0.001
20-Jul	2.93	7.48	6.63	13.39	29.82	3.95	<0.001
27-Jul	4.57	3.77	14.31	19.60	27.31	3.06	<0.001
3-Aug	10.44	19.40	20.66	30.85	34.45	2.47	<0.001
10-Aug	4.92	5.49	10.41	17.24	22.40	2.01	<0.001
17-Aug	12.90	17.03	18.21	19.58	22.41	1.89	0.001
24-Aug	5.35	13.11	11.48	23.04	22.18	2.73	<0.001
31-Aug	8.01	13.01	20.14	33.46	36.74	3.03	<0.001
7-Sep	8.51	13.42	17.11	26.41	32.17	2.51	<0.001
14-Sep	0.49	1.40	2.40	12.15	19.78	3.20	<0.001
21-Sep	1.46	7.66	7.05	17.52	38.31	4.02	<0.001
28-Sep	1.40	1.91	4.10	15.06	32.74	3.92	<0.001

Monitoring Media and Run-off pH and Electrical Conductivity (EC) During the Growing Season

The pH and EC of the run-off water was measured throughout the cropping season. Weekly measurements of run-off water pH are shown in Figures 48 and 49. Despite seasonal variability, the majority of the pH values recorded fell within the range of 7.5 to 8.5, irrespective of treatment. Until around early August, EC values for all treatments were generally similar, with some variation with sample date (Figure 50). EC for all treatments gradually increased until late August when treatment differences were much more apparent, i.e. the EC for the 20% run-off treatment declined, while for the 5% treatment it increased. Statistical analyses of these weekly measurements show that there was some variation in pH and EC with treatment (Tables 19 and

20). This was most apparent as a decline in run-off EC associated with treatments receiving the higher amounts of fertigation input (Table 20). The decline was apparent with the mean EC values collected at the end of the growing season (Figure 51, right). Mean seasonal treatment differences in run-off pH where small and not statistically significant, while EC treatment differences were apparent (Table 20).

Measurements where also made of the substrate pH and EC and these are shown in Figure 51. Measurements were made at the end of the season to avoid the need to remove compost samples and disturb the plants during cropping. Measured treatment differences in compost pH and EC were shown to be statistically different when determined at the end of the cropping season (Table 22). pH was more alkaline with the treatments receiving the larger amount of run-off, while EC was highest at the lowest run-off value. The marked decline in substrate EC, associated with the increased fertigation input, reflects the decline in EC measured in the run-off water (compare Figures 49, right and 51, right).

Table 20: Mean weekly measurements of run-off water pH taken throughout the cropping season

Week start date	5% run-off	10% run-off	15% run-off	20% run-off C	20% run-off N	SED	***f.prob***
22-Jun	7.81	7.94	8.26	7.88	7.88	0.182	0.155
29-Jun	8.15	8.36	8.91	8.53	8.62	0.172	0.004
6-July	8.14	8.20	8.04	7.85	7.65	0.066	<0.001
13-Jul	8.25	8.06	8.18	8.17	7.76	0.138	0.017
20-Jul	7.98	8.10	8.02	8.06	7.69	0.136	0.053
27-Jul	8.66	9.40	9.68	9.50	8.32	0.222	<0.001
3-Aug	8.37	8.86	9.03	9.03	8.00	0.1952	<0.001
10-Aug	8.51	8.62	8.78	8.39	7.89	0.155	<0.001
17-Aug	7.63	7.74	7.73	7.20	7.17	0.199	0.014
24-Aug	7.36	7.79	7.67	7.09	7.36	0.253	0.083
31-Aug	7.57	7.77	7.64	7.51	7.35	0.278	0.648
7-Sep	7.63	7.88	8.04	7.70	8.44	0.207	0.007
14-Sep	7.26	7.46	7.24	7.24	7.94	0.166	0.002
21-Sep	7.74	8.52	8.19	7.86	9.41	0.315	<0.001
28-Sep	7.10	8.10	7.49	7.36	9.02	0.300	<0.001

Table 21: Mean seasonal treatment differences in fertigation input, percentage run-off, run-off pH and EC (mS per 20 ^{0}C)

Treatment	5% run-off	10% run-off	15% run-off	20% run-off C	20% run-off N	SED	*f.prob*
Weekly input litres per week	24.3	33.2	36.2	48.2	46.7	0.32	<0.001
Run-off as % input	5.5	10.0	14.5	24.6	28.3	1.86	<0.001
pH	7.87	8.19	8.19	7.96	8.03	0.128	0.085
EC	4.58	3.88	3.51	3.05	2.72	0.331	<0.001

Table 22: Mean weekly measurements of run-off water EC (mS per 20 ^{0}C) taken during the cropping season

Week start date	5% run-off	10% run-off	15% run-off	20% run-off C	20% run-off N	SED	*f.prob*
22-Jun	3.13	2.22	2.01	1.89	2.08	0.2012	<0.001
29-Jun	3.84	2.55	2.31	2.10	2.18	0.369	<0.001
6-July	2.74	2.41	2.21	2.16	2.56	0.1676	0.014
13-Jul	3.08	2.40	2.19	2.13	2.52	0.2213	0.003
20-Jul	2.87	2.61	2.61	2.47	3.13	0.2338	0.076
27-Jul	4.30	3.12	2.58	2.55	3.37	0.355	<0.001
3-Aug	3.55	3.71	2.88	2.65	3.21	0.470	0.172
10-Aug	2.82	2.70	2.74	2.74	3.56	0.1918	<0.001
17-Aug	4.78	3.66	3.60	3.59	3.35	0.489	0.064
24-Aug	6.22	5.72	4.41	4.12	3.33	0.807	0.011
31-Aug	6.78	5.21	5.06	3.86	3.43	0.789	0.004
7-Sep	6.29	4.83	4.88	3.60	2.52	0.550	<0.001
14-Sep	5.67	4.36	4.78	3.76	2.53	0.717	0.004
21-Sep	4.88	5.29	4.91	3.92	1.53	0.520	<0.001
28-Sep	7.69	7.41	5.60	4.33	1.60	1.356	0.001

Table 23: Measurements of substrate pH and EC at the end of the season (October) expressed as mean per treatment

Treatment	5% run-off	10% run-off	15% run-off	20% run-off Control	20% run-off extra nutrient	SED	***f.prob***
Compost pH	6.22	6.28	6.30	6.45	6.60	0.080	<0.001
Compost EC uS per 20 deg.	1167	1133	1085	790	619	113.7	<0.001

Monitoring Compost Water Content

A '*ThetaProbe*' was used to routinely monitor, non-destructively, the volumetric water content of the growing media throughout the season, the results are shown in Figure 52. In general, the seasonal changes in compost moisture content were small averaging around 0.35 to 0.45 m^3 per m^3 of substrate. The lowest substrate water content was obtained in the 5% run-off treatment. On some occasions, particularly in late July and early August, this will have likely impacted on the cropping plants. Reducing the availability of water in the substrate will have reduced the plants water potentials and increased the level of leaf drought stress. Mild drought stress can reduce the plant's ability to lose water but often only at the expense of reducing photosynthesis and growth. Statistical analyses, of the substrate moisture data, show that when differences were apparent they were due to treatments which received less fertigation, having lower substrate moisture contents, i.e. drier (Table 24).

Table 24: Mean non-destructive measurements of substrate moisture content (m^3 m^{-3}) taken throughout the season with a DeltaT Devices, ThetaProbe

Treatment	5% run-off	10% run-off	15% run-off	20% run-off Control	20% run-off extra nutrient	SED	*f.prob*
16-July	0.35	0.32	0.37	0.42	0.41	0.022	<0.001
23-July	0.38	0.37	0.39	0.42	0.40	0.018	0.081
30-July	0.43	0.41	0.45	0.46	0.44	0.015	0.043
6-Aug	0.36	0.26	0.39	0.40	0.41	0.019	<0.001
20-Aug	0.37	0.35	0.37	0.37	0.37	0.020	0.806
3-Sep	0.44	0.41	0.44	0.45	0.46	0.017	0.067
17-Sep	0.27	0.19	0.29	0.34	0.41	0.020	<0.001

Monitoring Nutritional (nitrogen) Changes Through Non-destructive Measurements of Leaf Chlorophyll Content

To ensure that the bark loam compost mix was able to provide the plants with sufficient nutrition for optimal growth, an additional supply was made to treatment 5 by increasing the amount of 'Agrosol F316' added to the fertigation feed. Direct non-destructive measurements were also made of leaf chlorophyll content. Deficiencies in certain elements, in particular nitrogen, are rapidly reflected in a reduction in the amount of leaf chlorophyll a major 'sink' (user) for the plant's nitrogen. Leaf chlorophyll content was monitored on three occasions during the growing season and data are shown in Figure 40. There was a small, but significant difference in leaf chlorophyll content on August 20th which showed a decline with the increase in fertigation applied (Table 25). The increase in nutritional input (treatment 5) at the 20% run-off rate did not show a statistically significant increase in chlorophyll content.

Table 25: Non-destructive measurements of leaf chlorophyll content taken on three occasions during the cropping season

Treatment	5% run-off	10% run-off	15% run-off	20% run-off Control	20% run-off extra nutrient	SED	*f.prob*
11-Jun	25.5	25.7	24.9	26.3	25.0	1.30	0.815
9-July	24.7	23.1	23.4	23.1	22.4	1.01	0.256
20 August	26.6	28.0	24.4	24.3	24.0	1.11	0.006

Monitoring Nutritional Changes Through Destructive Measurements of Leaf Mineral Content

Also to determine if added fertigation had any impact on plant's nutritional balance, samples of plant tissue were taken for destructive chemical analysis. Measurements were made of leaf mineral concentrations mid-way during the growing season and suggest that there were no large differences associated with treatment (Table 26). Despite some statistically significant differences, a clear relationship with treatment was not overly apparent. There was, however, no indication that the addition of further nutrition was reflected in any increase in leaf nutrient content, i.e. compare the low run-off treatments with 20% with extra nutrients (Table 25). Of the mineral ions measured, there was also no clear evidence that excessive (toxic) nutrient accumulation (e.g. sodium and manganese) had occurred in leaves subject to the sub-optimal run-off treatments.

Table 26: Mean leaf mineral analysis from samples collected mid-way through the cropping season (Nitrogen, phosphorus, potassium calcium, magnesium and sodium are expressed as per cent (g $100g^{-1}$) dry matter, while manganese is as ug g^{-1})

Treatment	5% run-off	10% run-off	15% run-off	20% run-off Control	20% run-off extra nutrient	SED	***f.prob***
Nitrogen	1.18	1.34	1.23	1.32	1.32	0.089	0.316
Phosphorous	0.36	0.37	0.37	0.38	0.38	0.023	0.824
Potassium	2.27	2.39	2.33	2.52	2.56	0.068	0.001
Calcium	1.00	1.08	1.10	1.18	1.02	0.069	0.108
Magnesium	0.23	0.22	0.22	0.22	0.20	0.009	0.058
Sodium	0.019	0.019	0.023	0.033	0.018	0.0084	0.367
Manganese	82	32	152	148	39	69.5	0.280

A more detailed destructive analysis of substrate nutrition was undertaken at the end of the cropping season (Table 27). These results show, in general, that nutrient concentrations were highest in the substrate taken from the treatments receiving the least amount of fertigation. This is not unexpected, as high amounts of fertigation would be expected to leach out salts from the substrate. Statistically significant treatment differences were apparent for nitrogen, potassium, calcium, magnesium and sodium. The extra nutritional input treatment at the 20% run-off level did not show that nutrient accumulation was occurring in the substrate, either with respect to the treatments at the lower rates of input, or compared to the other treatment at the same level of run-off, i.e. 20%.

Production of Plant Biomass

Vegetative aboveground biomass was determined when the plants were harvested at the end of the cropping season in September (Figure 54). Figure 54 shows mean fresh and dry weights expressed on a per plant basis, while the data in Table 28 has been analysed on a per bench basis (10 plants per bench). Total fresh weights were measured for all the plants within the experiment and a proportion were oven dried at 80^{o}C until constant weight. Fresh weight analysis showed that the plants with the lowest run-off were statistically smaller, but there was no difference between any of the other treatments (Figure 54, top, Table 28). Analysis of the amount of aboveground dry matter showed little difference in plant mass with respect to treatment, but again it was the plants in the 5% run-off treatment that were the smallest, while those in the 20% run-off treatment (control) were the largest (Figure 54, bottom, Table 28). Again, there was equally no evidence to support the notion that increasing the fertigation had any influence on aboveground dry matter production, due to potential substrate nutrition limitation.

Table 27: Mineral analysis of substrate taken at the end of the season expressed as mean per treatment (All nutrient concentrations are expressed as ug g^{-1})

Treatment	5% run-off	10% run-off	15% run-off	20% run-off Control	20% run-off extra nutrient	SED	***f.prob***
Nitrogen	288	232	215	156	71	31.7	<0.001
Ammonium	0.166	0.087	0.097	0.156	0.056	0.0779	0.583
Potassium	611	619	604	501	396	36	<0.001
Calcium	612	567	523	317	239	93	0.002
Magnesium	158	146	133	84	64	22	0.001
Phosphorous	9.12	9.26	9.49	8.22	7.98	0.967	0.452
Iron	0.85	0.87	0.78	2.15	1.08	0.626	0.197
Zinc	0.252	0.246	0.206	0.079	0.069	0.0862	0.110
Manganese	0.032	0.021	0.013	0.008	0.001	0.0153	0.326
Copper	0.010	0.004	0.004	0.008	0.001	0.0050	0.464
Boron	0.095	0.068	0.074	0.062	0.053	0.0184	0.246
Sodium	284	295	286	225	189	26.2	0.002

Table 28: Means of above ground vegetative growth (runner number, crown number, non-fruiting truss number, immature fruit number, and fresh and dry total plant weight) recorded at the end of the growing season. Means were determined for each experimental bench i.e. 10 plants

Treatment	5% run-off	10% run-off	15% run-off	20% run-off Control	20% run-off extra nutrient	SED	*f.prob*
Runner no.	38.8	39.5	34.0	38.5	43.2	4.08	0.311
Crown no.	91.8	105.5	112.7	116.8	112.7	7.76	0.034
Non-fruiting truss no.	55.2	50.7	63.2	71.3	68.8	8.63	0.121
Immature fruit no.	230	347	275	312	271	37.4	0.054
Fresh wt. (g)	2275	2932	3033	3334	3118	227.2	0.002
Dry wt. (g.)	631	693	655	843	685	53.3	0.077

As the experimental material was still flowering and cropping, when the experimental harvest was carried out, the number of 'reproductive structures' still present on the plants was recorded. With the exception of crown number, which was significantly reduced at the 5% run-off level, there were no significant differences in the numbers of reproductive structures. There were no significant differences detected with the number of immature fruit, non-fruiting trusses and runners produced per plant (Figures 55 and 56).

Crop Production

The weekly total weight of crop per treatment and number of fruit picked (60 plants per treatment) are shown in Figure 57. Production rapidly increased in late June, after plant establishment. By the time of maximum production rate in August each plant, for the 10% run-off treatment and above, was producing about 20g of fruit per week. By the end of August fruit production had severely declined, this was much earlier than in previous years. The seasonal pattern of fruit production was similar irrespective of treatment or data expression, i.e. fruit weight or number (Figure 57 top and bottom). There was however treatment differences with respect to rates of crop production. Plants within the lowest run-off treatment cropped over the season on average at just under 1 kg per plant, while those at the 20% run-off level yield just over 1.4 kg per plant.

Table 29: Mean total crop weight (g) for the entire season for fruit of different size (35+mm, 25-35mm, 22-25mm and waste fruit including fruit less than 22mm, misshapen and rots). Mean totals are for each experimental bench, i.e. 10 plants

Treatment	5% run-off	10% run-off	15% run-off	20% run-off Control	20% run-off extra nutrient	SED	*f.prob*
35+mm	1161	1797	1919	2509	2327	291.4	0.002
25-35mm	5336	6847	7241	8847	8183	472.5	<0.001
22-25mm	2390	2774	3059	3096	3228	212.5	0.006
Waste	315	322	333	334	345	52.2	0.980
Total	9202	11740	12552	14786	14083	677.4	<0.001
Total Class1 fruit	6497	8644	9160	11356	10509	706.2	<0.001
Percentage class 1 fruit	70.32	73.50	72.76	76.75	74.29	2.408	0.153
Percentage waste	3.47	2.77	2.69	2.28	2.52	0.503	0.224

By the end of June, plants from the treatment with the lowest level of run-off (5%) showed reduced fruit weight and numbers (Figure 57). This pattern was continued through the bulk of the season's production phase. The 10% run-off treatment was less dramatically influenced by fertigation compared to the 5% treatment, particularly in the early part of the season. It was not until early August that fruit production declined rapidly with plants in the 10% treatment. By late August all treatments showed a rapid and similar rate of seasonal decline in cropping.

Statistical analyses of the mean weekly totals of fruit weight or number are shown in Tables 30 and 31. A general pattern is evident that shows treatment differences appeared in late June. By mid July through to August, these statistical differences were large (P>0.001) and consistent. This pattern of cropping differences was directly related to the amount of run-off a treatment received, i.e. crop number or weight was greatest for the 20% run-off treatment, followed by the 15% treatment, then the 10%, while the 5% treatment had the smallest crop (Tables 30 and 31).

Seasonal analysis of the picked crop, with respect to fruit quality (size), is shown in Figures 58 and 59. For the class 1 and 2 fruit there was a general increase in fruit weight with increasing level of run-off (Figure 58). For fruit within the waste class (small, misshapen fruit and rots) there were no obvious treatment differences. All the of size classes of fruit showed seasonal changes, large fruit (>35mm) peaked very early in the season, while fruit in the next class and class two were produced at their maximum rates only in mid August. It was around this time that the maximum production of waste fruit occurred. When these data were expressed as a proportion of the total crop it was evident that the 25-35mm class showed the greatest treatment difference (Figure 59).

Table 30: Mean total number over the entire season for fruit of different size (35+mm, 25-35mm, 22-25mm and waste including fruit <22mm, misshapen and rots). Means are for each bench, i.e. 10 plants

Treatment	5% run-off	10% run-off	15% run-off	20% run-off Control	20% run-off extra nutrient	SED	***f.prob***
35+mm	53.2	84.0	88.3	116.2	106.5	12.93	0.001
25-35mm	518	662	703	843	790	41.9	<0.001
22-25mm	478	556	605	620	656	43.5	0.006
Waste	171.3	182.3	182.0	180.7	183.3	29.74	0.994
Total	1220	1484	1578	1760	1736	72.0	<0.001

Table 31: Mean total crop weight (g) per week per treatment. Means are for each bench, i.e. 10 plants

Week start date	5% run-off	10% run-off	15% run-off	20% run-off C	20% run-off N	SED	*f.prob*
1-Jun	122	141	158	174	166	30.1	0.453
8-Jun	185	208	204	186	225	38.3	0.821
15-Jun	111	147	120	93	148	34.2	0.451
22-Jun	426	411	387	475	508	58.5	0.266
29-Jun	531	631	669	791	741	82.5	0.044
6-July	595	768	780	933	817	124.2	0.147
13-Jul	735	1052	972	1255	1101	123.0	0.007
20-Jul	900	1239	1355	1727	1523	156.7	<0.001
27-Jul	713	1119	1102	1338	1277	115.5	<0.001
3-Aug	1310	1920	1952	2133	2151	143.9	<0.001
10-Aug	1212	1725	1751	2141	1967	122.2	<0.001
17-Aug	820	887	1255	1467	1368	159.8	0.001
24-Aug	518	542	724	830	804	101.7	0.014
31-Aug	307	269	358	425	362	47.7	0.039
7-Sep	360	245	307	366	417	66.9	0.146
14-Sep	154	102	143	147	203	44.9	0.310
21-Sep	108	168	153	139	163	66.4	0.901
28-Sep	95	166	160	164	144	54.7	0.670

Fruit quality was generally very consistent irrespective of treatment. The amount of waste was small, less than 14% of the total crop, and was slightly higher for the 5% treatment compared to the 20% run-off treatment (Figure 47, top). However, the proportion of the crop, which achieved a size class 1 grade, was very consistent with all treatments at 70% of the total crop (Figure 47, bottom).

Statistical analysis of the cropping classes is shown in Tables 29 and 30. There were statistically significant treatment differences for the total crop and the top three size classes, but the for the waste class there were no differences. This was true, irrespective if crop weight or fruit number were used in the analyses.

Table 32: Mean total fruit number per week per treatment. Means are for each bench, i.e. 10 plants

Week start date	5% run-off	10% run-off	15% run-off	20% run-off C	20% run-off N	SED	*f.prob*
1-Jun	9.00	9.50	10.50	11.33	10.50	1.778	0.711
8-Jun	14.67	16.00	15.83	15.17	17.50	2.607	0.848
15-Jun	12.17	11.50	12.50	9.83	12.67	2.810	0.850
22-Jun	25.2	22.3	21.7	21.5	24.5	3.48	0.757
29-Jun	40.2	39.3	43.0	48.0	44.8	5.10	0.452
6-July	56.0	67.5	65.3	72.5	63.2	7.94	0.355
13-Jul	89.7	115.2	99.8	122.2	109.2	11.90	0.094
20-Jul	119.0	152.0	164.8	189.8	178.8	14.93	0.001
27-Jul	96.3	138.7	140.2	167.5	167.0	13.16	<0.001
3-Aug	175.8	254.3	253.3	273.5	292.0	17.30	<0.001
10-Aug	192.7	257.3	251.7	271.8	276.7	17.22	<0.001
17-Aug	127.3	139.7	187.8	204.2	203.5	21.83	0.003
24-Aug	75.7	84.0	110.3	119.0	118.7	15.21	0.024
31-Aug	51.0	50.0	62.8	73.2	58.3	9.07	0.107
7-Sep	59.3	44.2	57.5	68.0	67.8	12.29	0.318
14-Sep	31.7	21.3	25.3	32.3	36.5	7.96	0.363
21-Sep	23.7	30.7	26.7	30.3	28.5	11.59	0.972
28-Sep	21.0	30.5	28.5	29.3	26.0	10.19	0.891

Discussion

Treatment differences in the amount of fertigation run-off varying from 5 to 20% of the input values were achieved, but not without detailed and extensive adjustment to conventional irrigation practice. The approach was also based on detailed and time consuming observations of plant water usage and manual adjustments to fertigation rates. Control systems to determine plant water usage are becoming available (evaposensor etc.) and subsequent research should explore their potential for use by the strawberry industry. The amounts of run-off wastage achieved reflects differences between supply (input) and use (primarily plant transpiration) and are therefore not simply determined or predicted. It will vary considerably with daily climatic (temperature and solar radiation) changes within the polytunnel and this is a primary limitation to prediction.

The pH and EC values determined for the run-off water varied with treatment. Most noticeable EC, as might be expected, was much higher where the fertigation input was lowest and run-off least. This is most likely a reflection of the general build up of minerals ions, by evaporation and the plants using the water, within the 'grow bags' and the subsequent release of a small volume of concentrated run-off during fertigation. The changes in substrate pH and EC again as might be expected, the lowest level of run-off induced an increase in substrate EC, which was raised further as the season progressed. This being a reflection of the build up of mineral ions within the compost that are surplus to the plant's demand and remain in the growing media if not washed out. Normal industry practice would be to maintain high levels of fertigation input to achieve high substrate through-put of water (20% run-off) to wash out excessive ions and avoid plant toxicity.

It is of considerable interest that this increase in substrate EC did not however produce any obvious detrimental plant stress symptoms, despite the reasonably lengthy growing season. The general trend for a very rapid end to the cropping season, evident as a rapid decline in fruit production rate, was clearly a factor unrelated to substrate EC, as all treatments irrespective of

EC showed the same phenomenon. This may have been due to the fact that the season has been so warm and the plants cropped so heavily that they were 'burned out' and rapidly senesced.

A more likely explanation for the lower cropping levels observed with the very sub-optimal run-off levels (5%) may be drought stress. In general, the other treatments maintained consistently similar substrate moisture contents, throughout the growing season. For the 5% run-off treatment there was some evidence that substrate water content on certain dates may have been low enough to induce an increase in plant water stress. This is not certain, as leaf water potentials were not measured, but again the season was very warm and sunny and such conditions make large demands on plant water use. It was noted in the details of the crop analysis that, even within the lowest run-off treatment, some plants did as well as those that were supplied with considerably more fertigation. It seems that one of the major problems associated with attempts to reduce fertigation wastage may be achieving an even distribution of a small amount of water. The more plants per bag and the larger the grow-bag the more difficult this problem is likely to become.

Enhancing the nutrition of the fertigation supply had no impact on any of the mineral ions measured in leaf material from 'Everest' plants. Equally, there was no evidence to suggest that leaf chlorophyll content had been enhanced. This suggests that the supply of nutrients, and possibly nitrogen, at the standard rate was more than adequate with respect to optimising leaf chlorophyll content when in this bark/loam substrate (90/10 v/v). This supports earlier work with 'Everest' in standard peat-based media.

The results from the assessment of plant biomass suggest that plant fresh weight may have been slightly reduced at the lowest level of run-off, but this did not have a major impact of aboveground plant dry matter production. It does, however, agree with the possibility that reduced substrate moisture levels, measured on some occasions, may have impacted on crop water content. This supports the possibility that a reduced plant water content, at the low level of run-off, may have had a detrimental influence on crop production.

Crop production rate was shown to be reduced for plants within the 5% run-off treatment and to a lesser extend in the 10% run-off treatment, particularly, towards the end of the cropping season.

It was noted however that even within the low run-off treatments that some plants achieved greater than 1.5 kg of fruit per plant over the season. This highlights a difficulty, when attempting to minimise water wastage and run-off contamination. It is not easy to ensure, in relation to the number of drippers, that a small total volume of water can be equally distributed within the grow-bag. In some cases failure to yield well could be simply linked to the position or distance of a plant from its nearest dripper. For example, plants that were at each end of the bag frequently tended to have the lowest yields. Further work, to increase the efficiency and uniformity of delivery of water is an area for future evaluation.

Seasonal cropping levels were very high on a per plant basis between 0.9 and 1.40 kg per plant. The lower crop yields for the 5% run-off treatment appeared to be associated with a smaller number of fruit, i.e.120 per plant compared to 170 for the 20% run-off treatment. The analysis carried out indicates that reducing run-off reduces fruit number in the absence of a reduction in fruit size. Conserving fertigation would therefore impact on yield but the influence on fruit quality is small. This is particularly true for the 10 and 15% run-off treatments, where the impact on yield was less evident compared to the 5% treatment. Further work to determine the cost-benefit of the excessive fertigation input relative to the additional yield would determine the commercial value of any desire to reduce run-off.

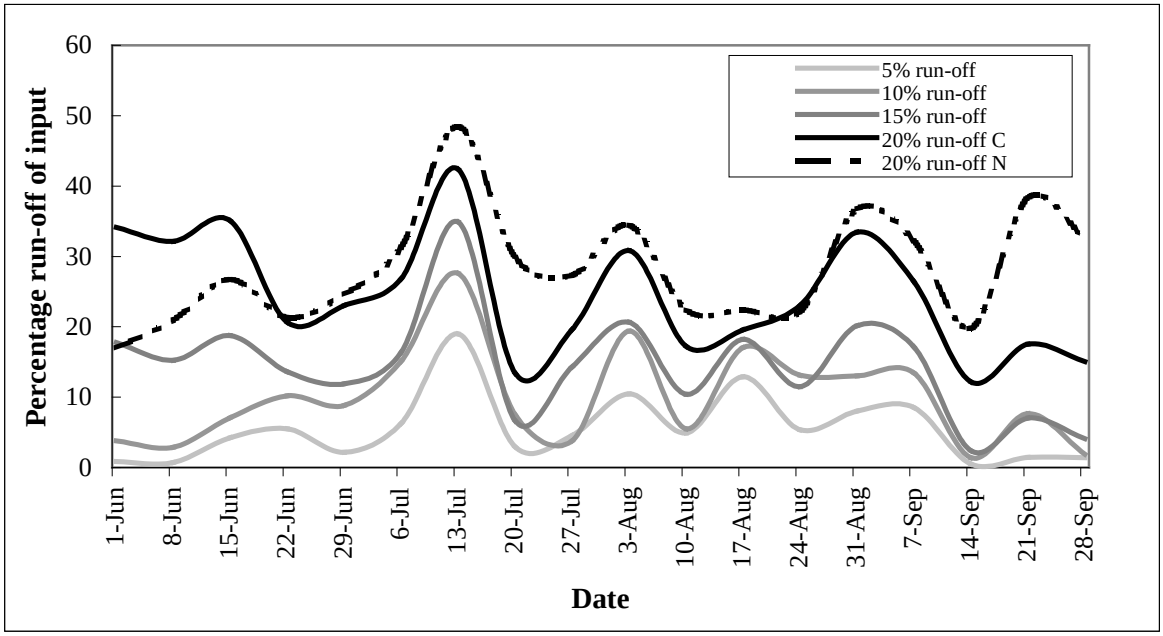


Figure 46. Weekly mean amounts of run-off expressed as percentage of the input measured throughout the cropping season.

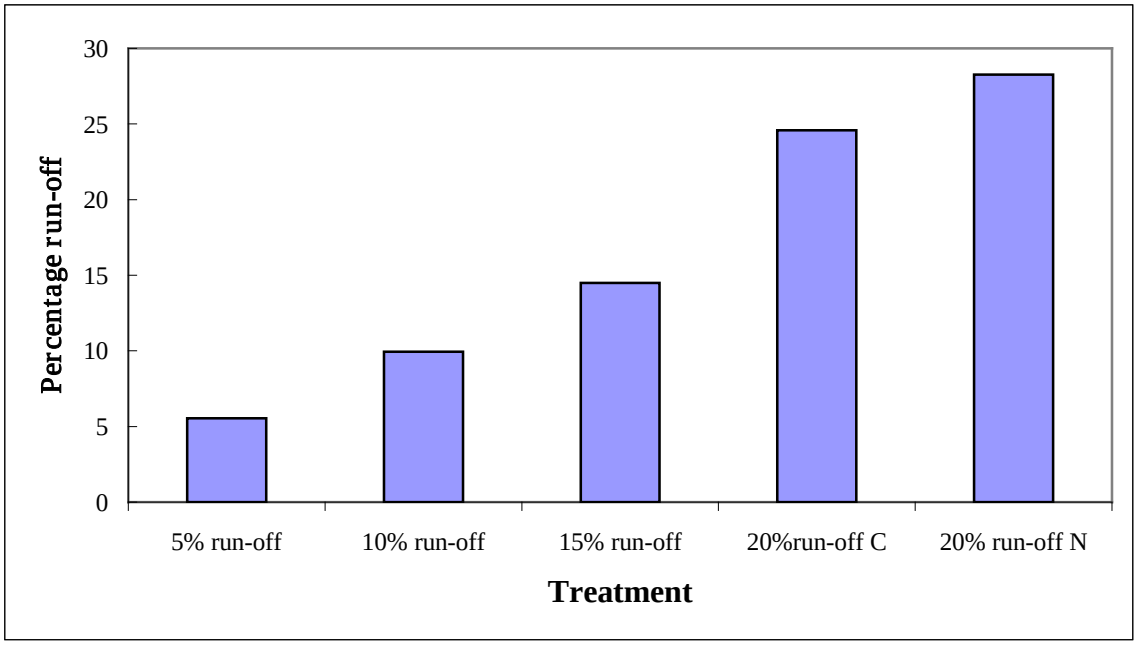


Figure 47. Treatment differences in the amount of run-off recorded as a percentage of the input volume (litres).

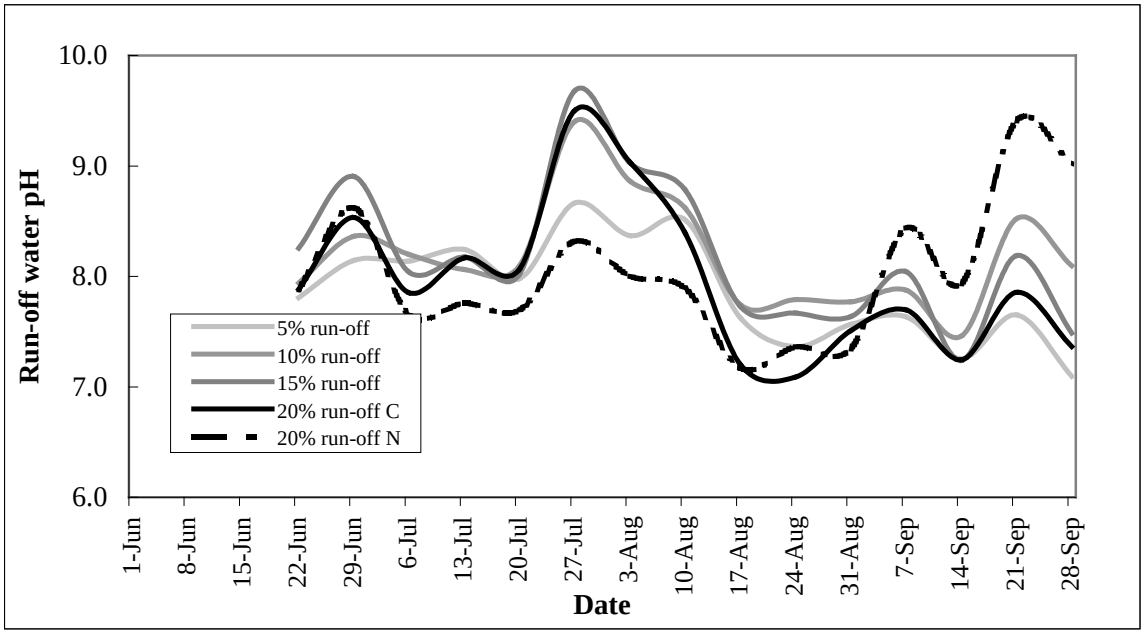


Figure 48. Weekly measurements of run-off water pH measured throughout the cropping season.

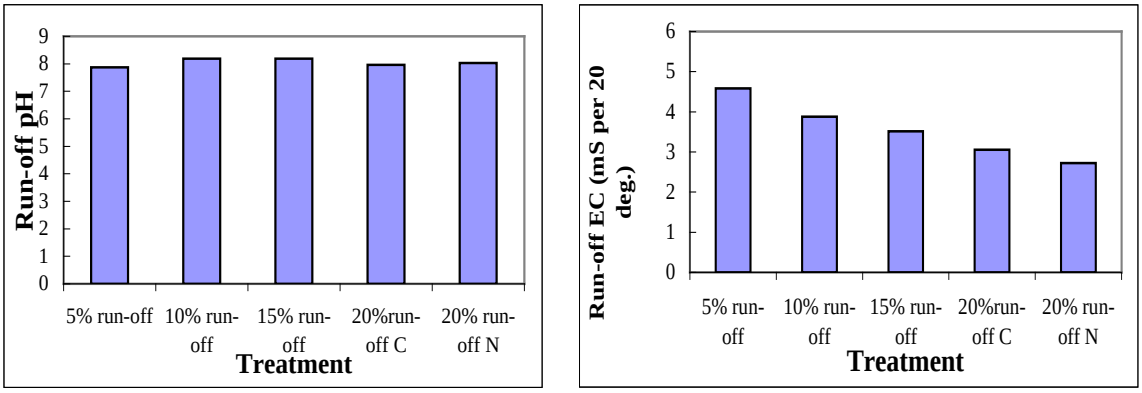


Figure 49. Treatment differences in run-off pH (left) and electrolytic conductivity (EC) (right) at the end of the cropping season.

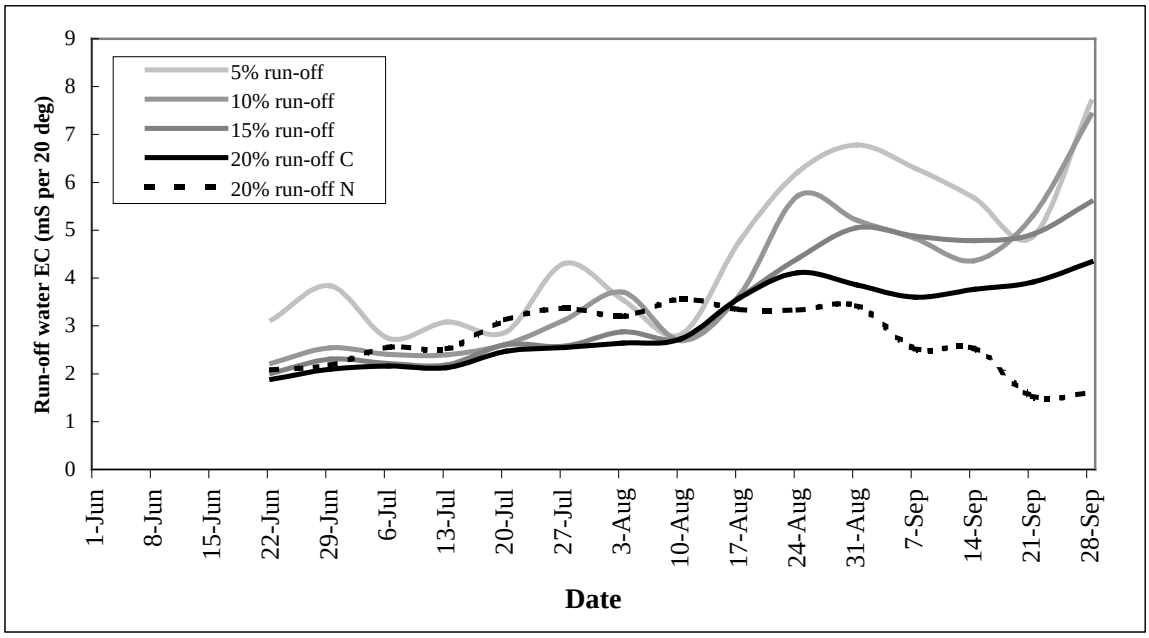


Figure 50. Weekly measurements of run-off water electrical conductivity (EC) throughout the cropping season.

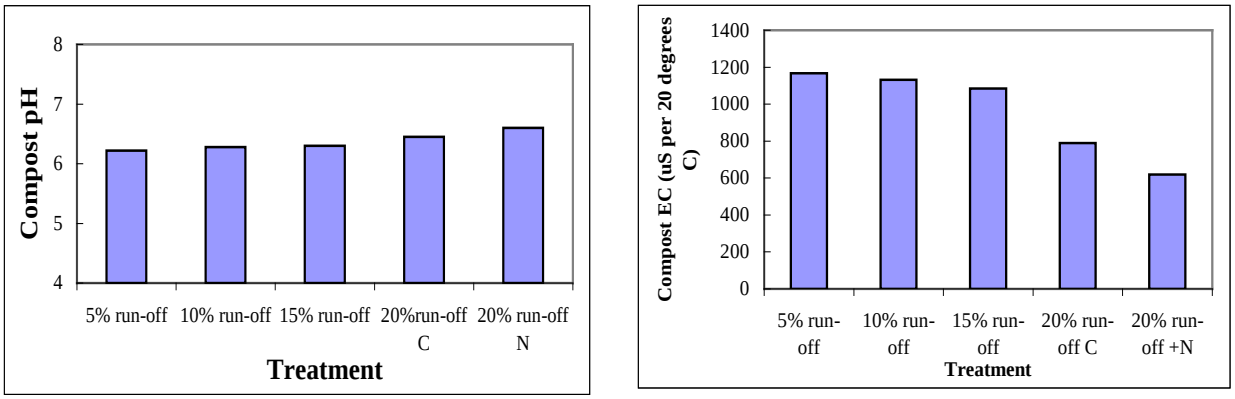


Figure 51. Treatment differences in compost pH (left) and electrical conductivity (EC) (right) measured at the end of the cropping season.

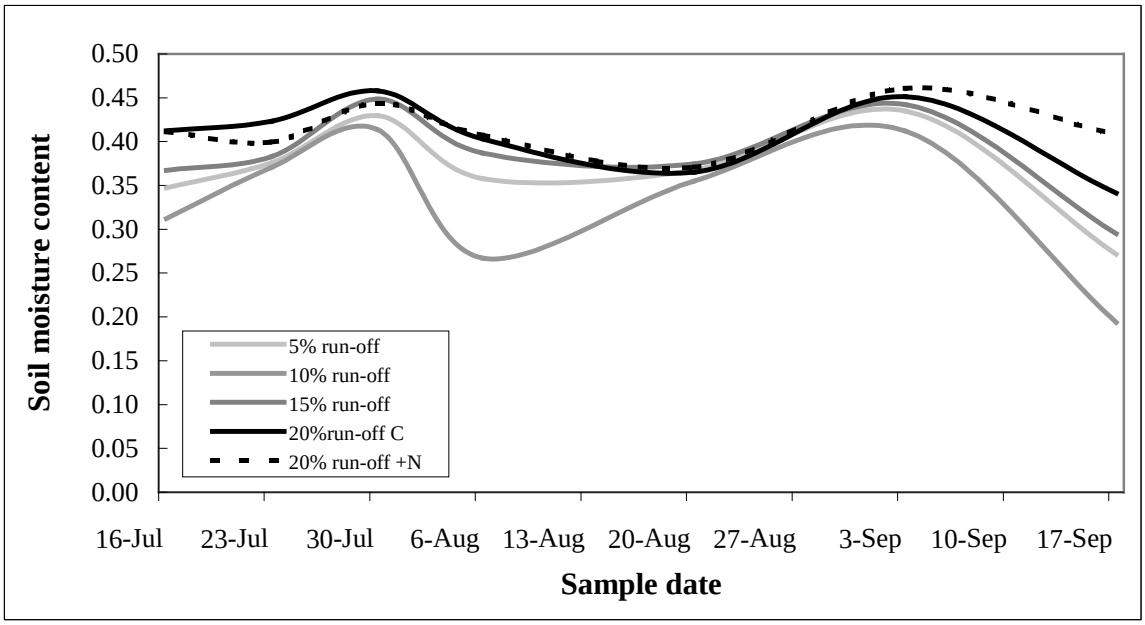


Figure 52 Non-destructive measurement of substrate volumetric water content (m^3 m^{-3}) made with a ThetaProbe (Delta-T Instruments) at fortnightly intervals for each treatment

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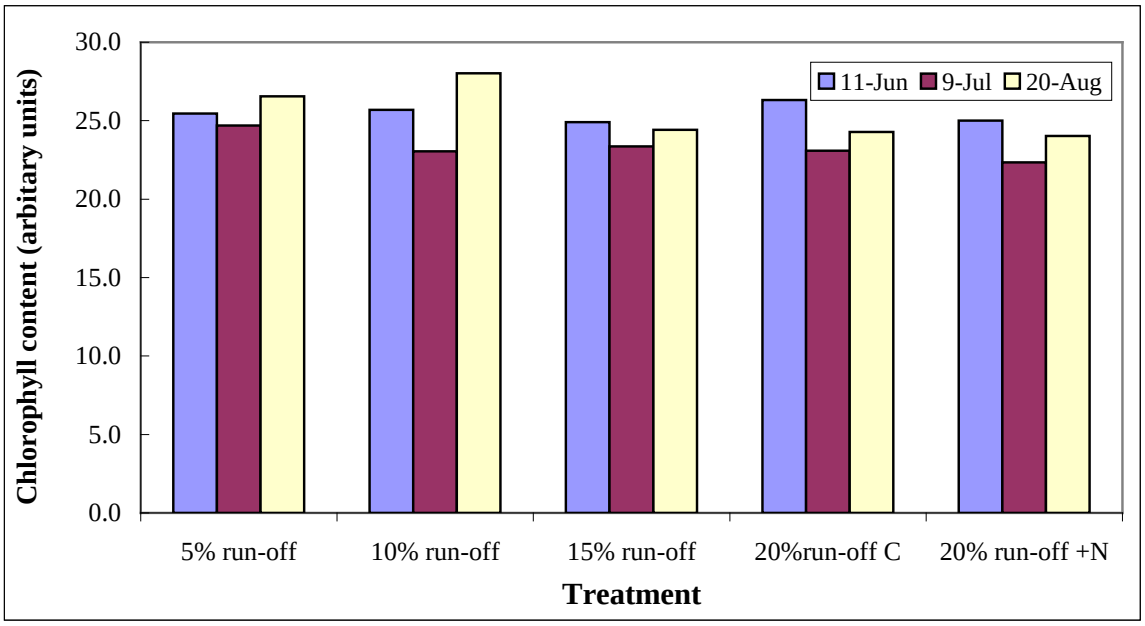
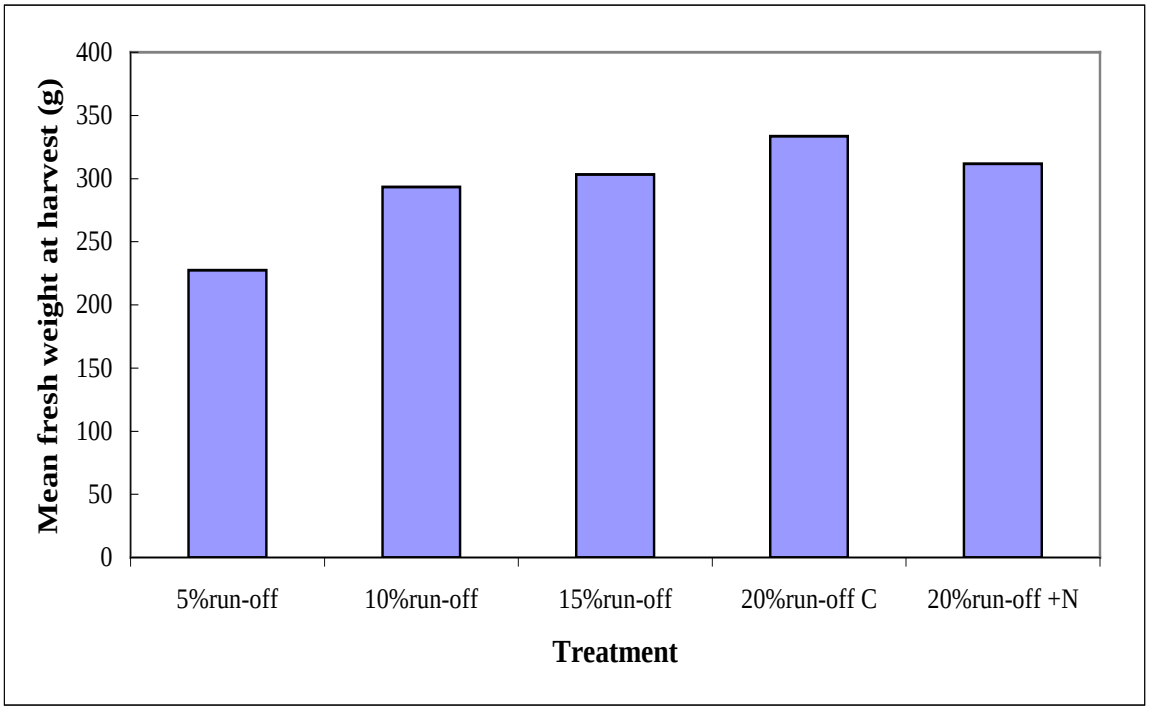


Figure 53. Non-destructive leaf chlorophyll measurements made with a chlorophyll content meter during the cropping season.



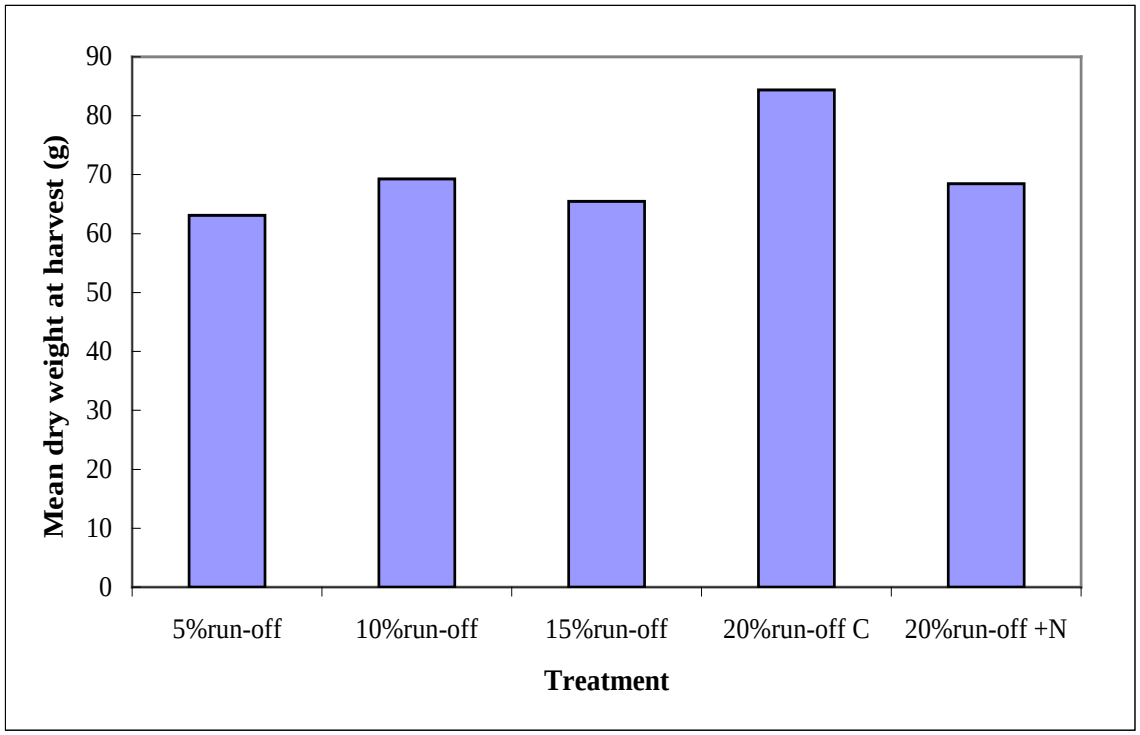


Figure 54. Mean fresh (top) and dry weights (bottom) per plant of above ground vegetative plant parts determined at the end of September when the plants were harvested.

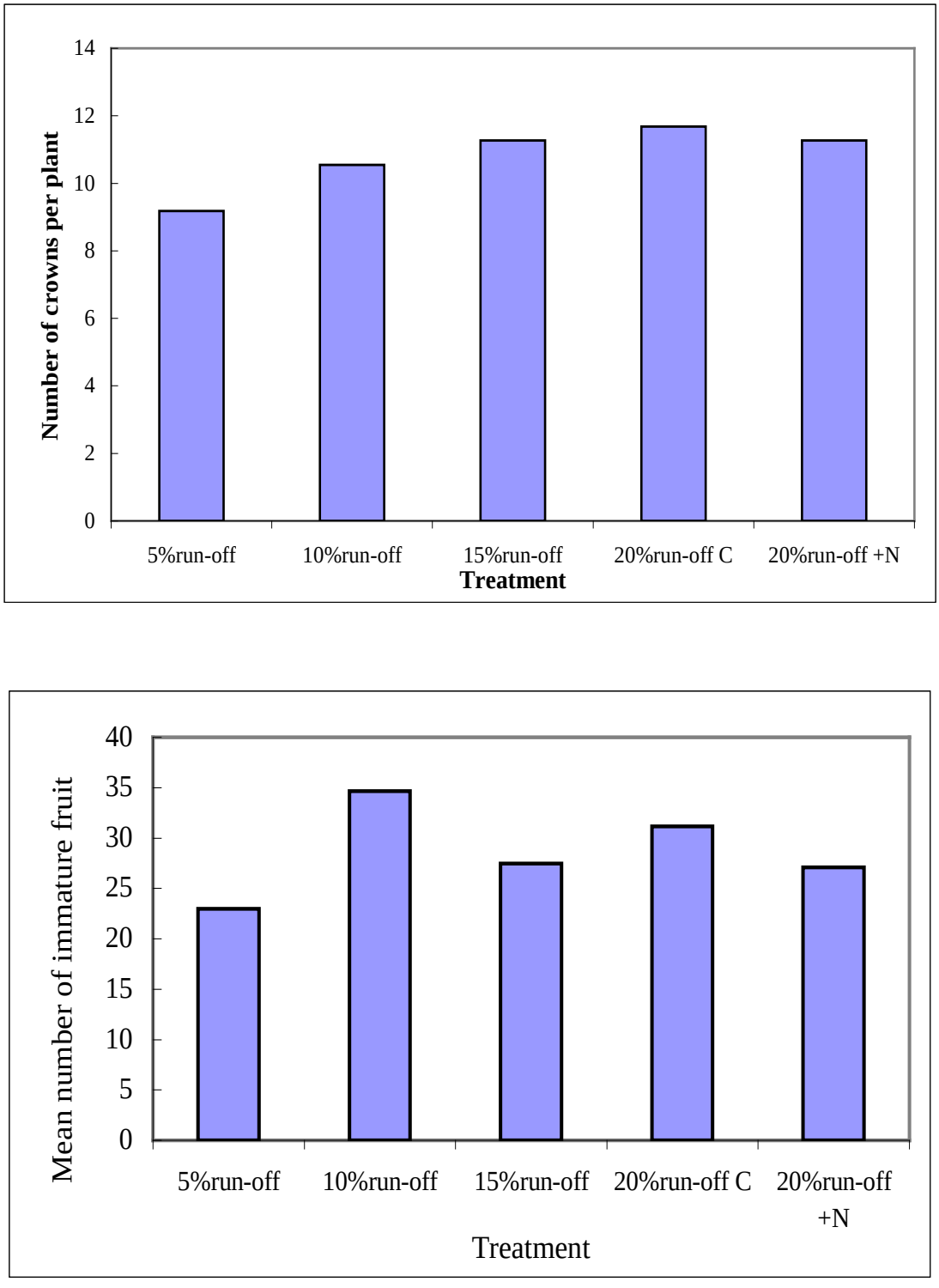
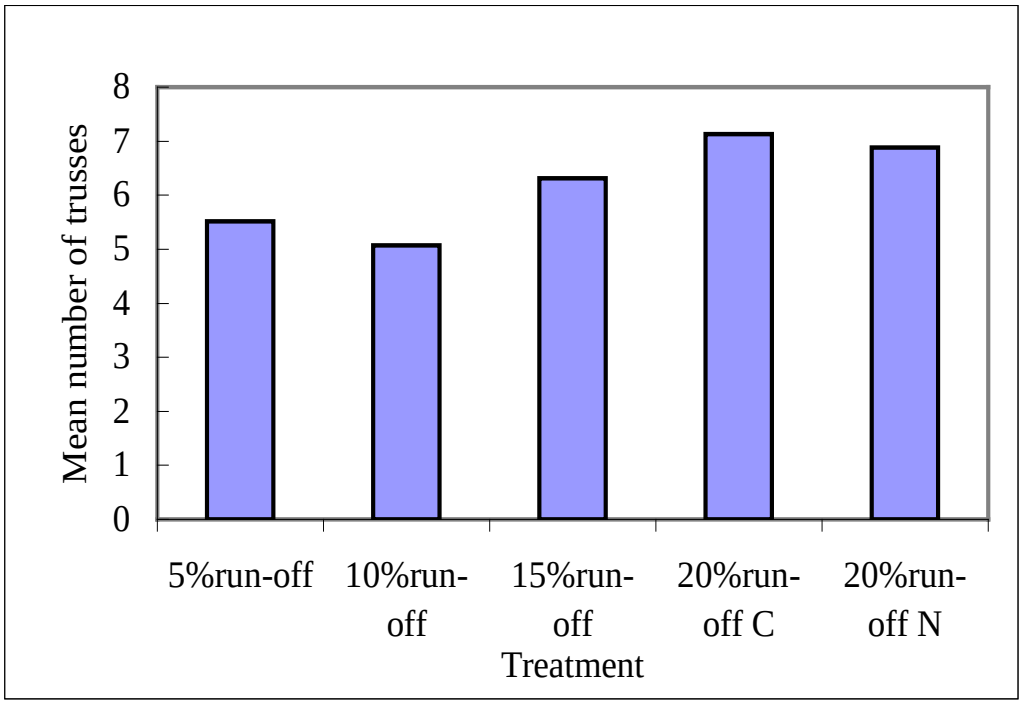


Figure 55. Numbers of crowns (top) and immature fruit (bottom) per plant still present at harvest time in September when the plants were harvested.



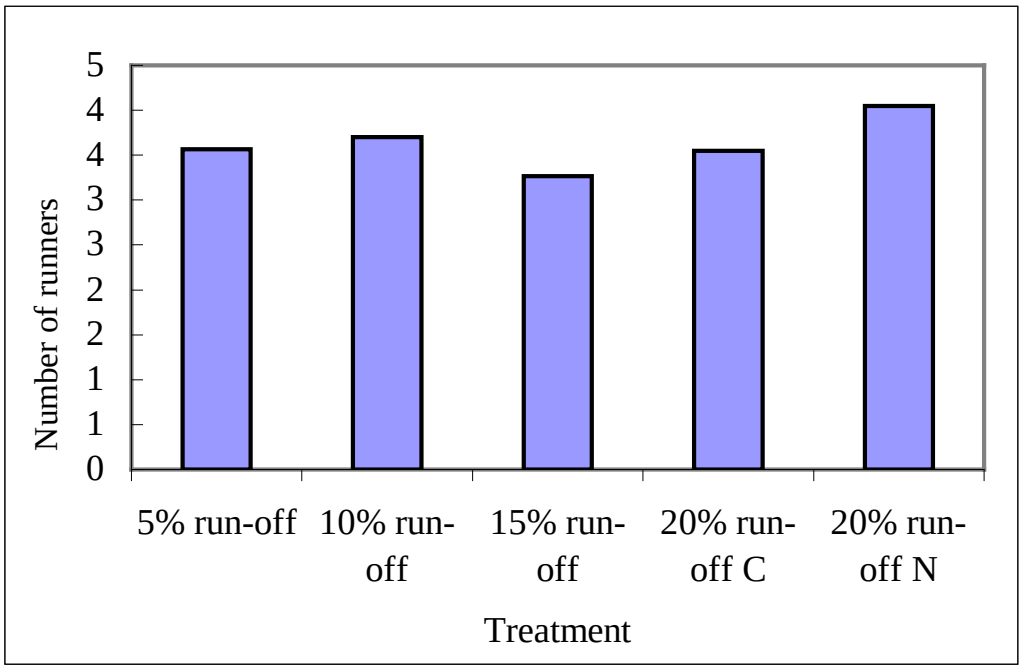


Figure 56 Mean number of non-fruiting trusses per plant at harvest in September (top) and runners produced per plant over the entire season (bottom).

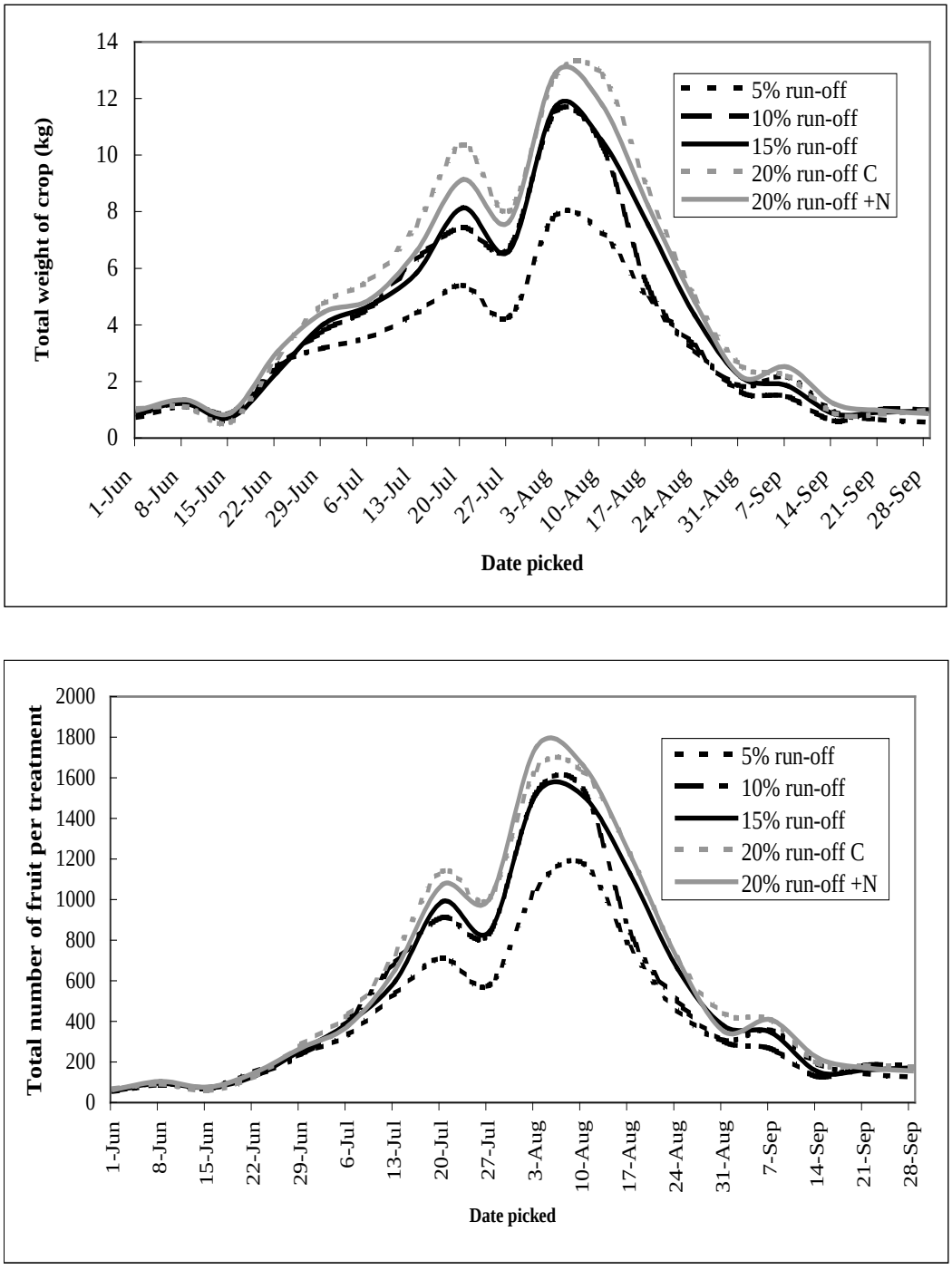


Figure 57. Mean weekly total crop weight (kg, top) or number (bottom) picked per treatment throughout the cropping season.

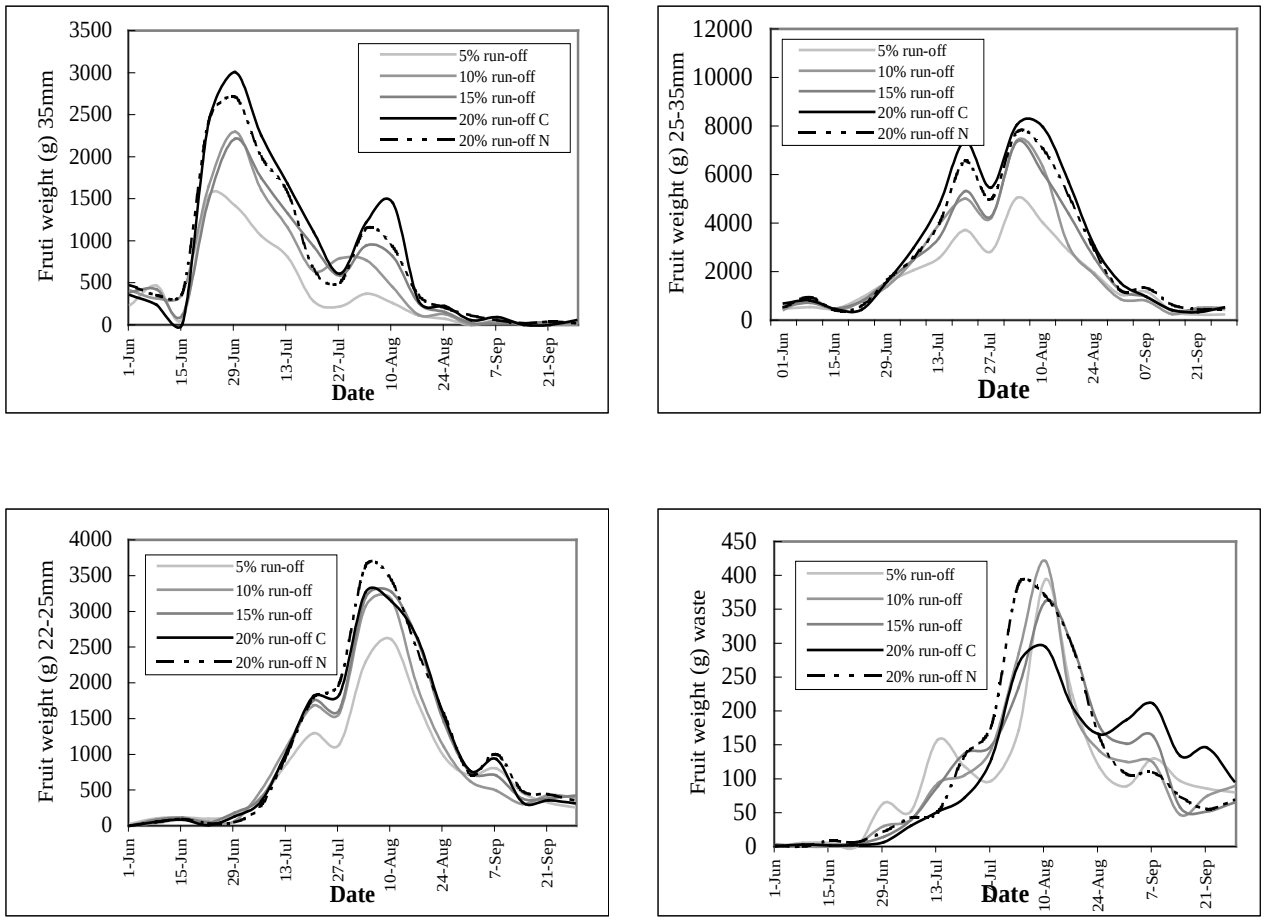


Figure 58. The seasonal changes in mean weekly crop totals per treatment, with respect to size quality class. Fruit were picked to various size classes, i.e. greater than 35mm class 1 (top left), 25-35mm class 1 (top right), 22-25mm class 2 (bottom left) and waste (less than 22mm, rots and misshapen, bottom right).

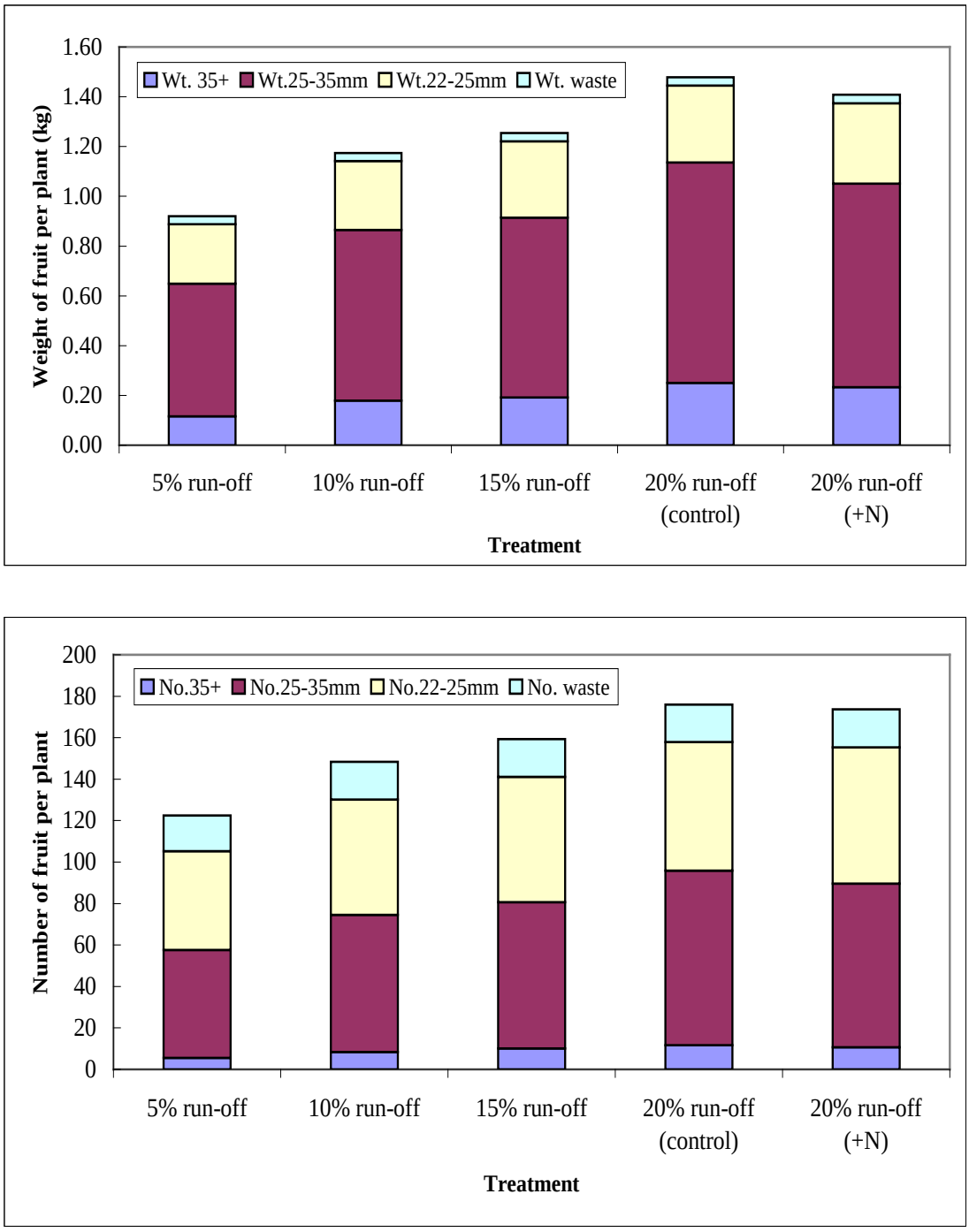
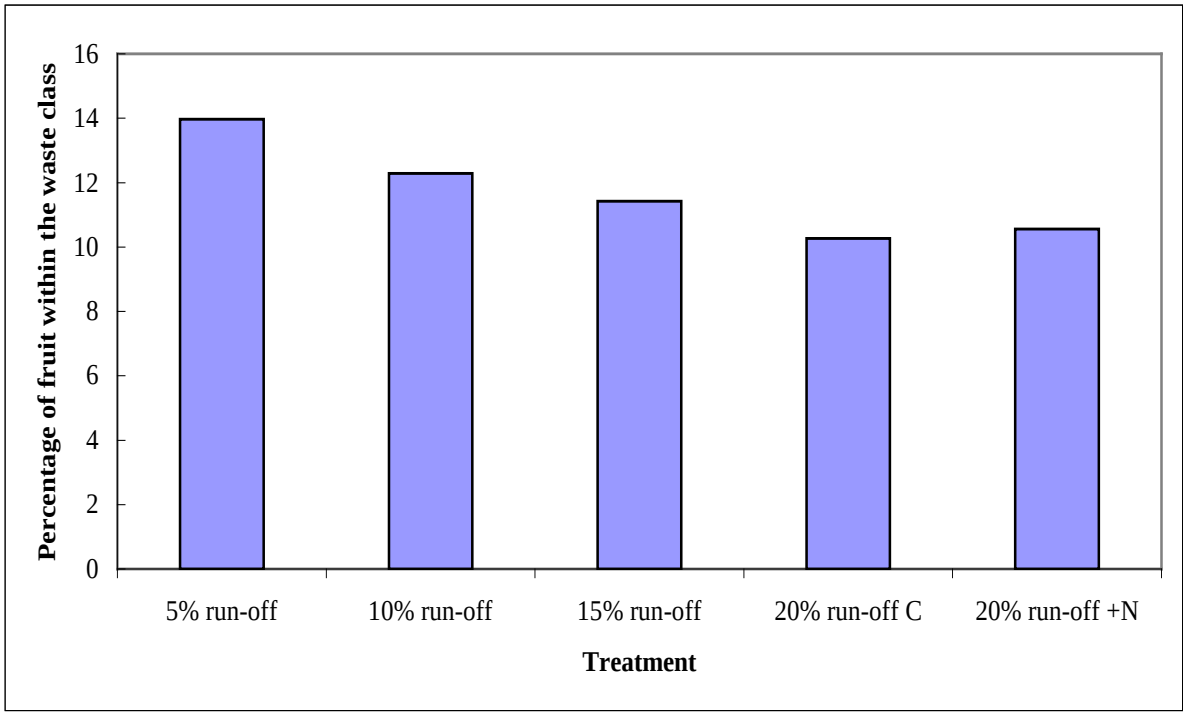


Figure 59. The total weight (top) and number (bottom) of seasonal crop, picked per plant, shown with respect to the distribution of fruit size. Fruit were picked to various size classes, i.e. greater than 35mm class 1, 25-35mm class 1, 22-25mm class 2 and waste (less than 22mm, rots and misshapen).



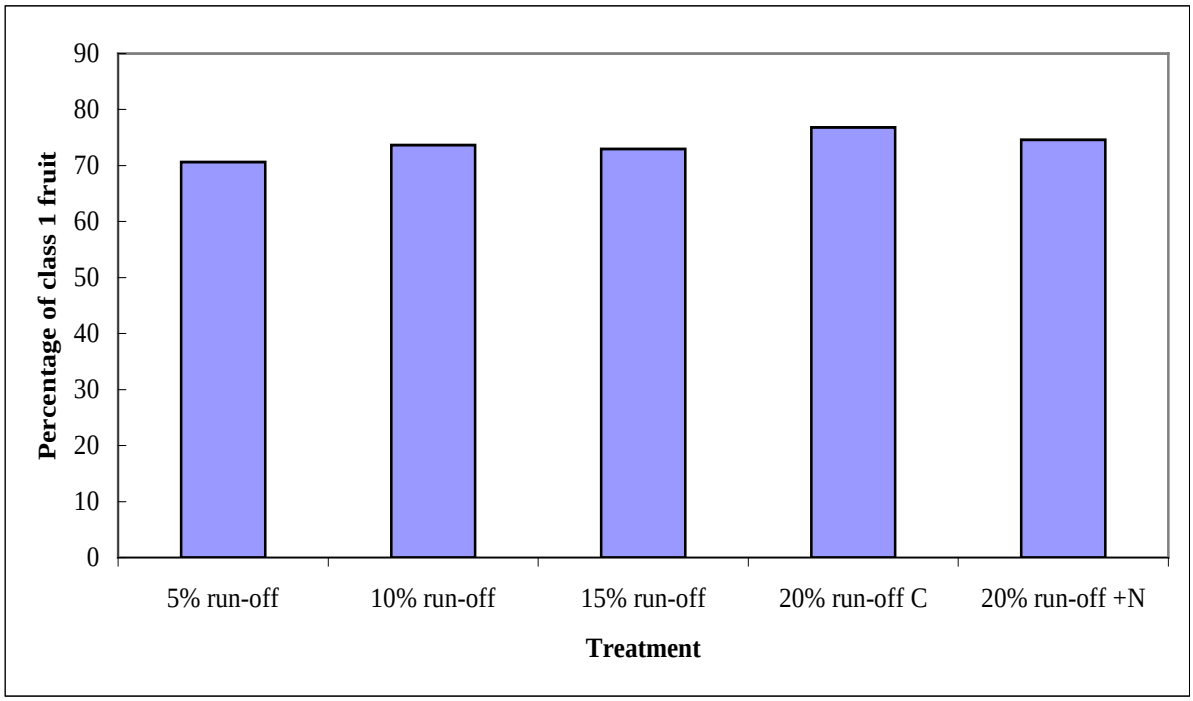


Figure 60. The percentage of the entire seasonal crop recorded within waste class (rots and misshapen) (top) and the class 1 (a combination of the greater than 35 mm and 25-35 mm fruit measurements) (bottom) for each treatment.

Conclusions

Initial analysis of media (Experiment 1) showed that alternatives to peat had acceptable physical and chemical characteristics. The pH in peat alternatives was generally higher, but these also have a greater chemical buffering capacity, so nutrient availability is adequate.

There was evidence (Experiments 3 and 5) that substrates based on composted bark immobilised nitrogen, presumably as decomposition continues during the cropping period. The importance of this is questionable, since nutrients are continually supplied in fresh solution under commercial production conditions.

Additional nitrogen in non-peat media (Experiments 5, 6 and 7) gave no yield advantage. This suggests that the under-performance of non-peat media is not related to sub-optimal nitrogen supply through nitrogen immobilisation.

Generally, effects of growing media were greater on fruit size than fruit number. For example, in Experiment 6, fruit in the peat treatment were larger, resulting in more fruit in Class 1 grade.

In Experiment 7, lower run-off resulted in higher electrical conductivity, but there was no indication of phytotoxicity. However, lower run-off increased the risk of drought stress, so more careful control of irrigation and lower spatial variability in both water supply and water demand would be desirable.

There is a need to understand the factors that cause peat to perform better than other growing media. Nitrogen nutrition does not appear to be a key factor, but further work is needed to investigate effects of other nutrients and also physical characteristics.

OBJECTIVE 4

Determine The Factors Influencing Plant Quality During The Pre-Planting Phase

The aim of this objective is to determine the factors influencing plant quality during the pre-planting phase, which will allow planting material to be pre-conditioned to produce maximum yields of Class 1 fruit within the novel growing system. There are three main sections to this objective:

- *Determine the Effects of Chilling on Junebearer Plant Performance*
- *Determine the Effects of Chilling on Everbearer Plant Performance*
- *Assess the Effects of Runner Variability on Plant Performance*

Determine the Effects of Chilling on Junebearer Plant Performance

Introduction

The research described here was concerned specifically with 'Elsanta' as the current, long-standing commercial favourite. It aimed to ascertain whether season extension using a combination of basic environmental prompts could be viable for this favoured cultivar without compromising plant health, fruit quality or total yield.

The work concentrated on using different combinations of chilling and day-length to manipulate fruiting. Considerable evidence existed to suggest these environmental factors are significant in 'Elsanta's' physiology, although the trade-off between successful cropping manipulation and detrimental vegetative effects was less clear. Different combinations of both cold storage temperature and duration were used to give varying degrees of chilling according to a previously described chill unit model (Tehranifar, 1997; Battey *et al.*, 1998). This was done in association with the use of artificial long-days (night-break lighting) and field chilling.

The overall objective was to provide the strawberry industry with a detailed knowledge of the feasibility of maximising fruit production and cropping period extension in the main Junebearing cultivar. With economic practicality in mind, the research was carried out under as near

commercial conditions as are possible in an experimental context. Finally, it was anticipated that the information gained for 'Elsanta' would be at least partially applicable to other Junebearing cultivars.

General Methodology

All experiments were carried out in a polytunnel at the School of Plant Sciences' Field Unit, Cutbush Lane, Shinfield. Plants were exposed to natural light intensity throughout the experiments except in the final experiment (Task 4.5 – experiment 3) when artificial night-break lighting was supplied during the winter period.

Following planting, plants in each experiment were arranged in a completely randomized design. Guard plants were grown at the end of the polytunnel nearest the ventilation fan and did not form part of the experiment. The polytunnel, which measured 18m by 8m (approx. 3.5m high), was covered with Polytherm plastic (BPI (Agric.), Stockton-on-Tees, England). The Polytherm was determined to be R/FR neutral using a red to far-red meter (SKR 110/100 Skye Instruments Ltd., Powys, U.K.). The polytunnel contained three wire mesh-covered benches on concrete supports running down its length upon which the plants were placed. In experiment 1 (Task 4.1), the bags were positioned across the benches at 45cm spacing between bags. In all other experiments, the bags were positioned lengthways along each side of the benches, lying end-to-end.

After planting the polytunnel was set to heat at 11°C and vent at 15°C during the winter and early spring period, to prevent the plants from receiving further chilling whilst allowing plant establishment. The polytunnel was re-set to heat at 16°C and vent at 20°C for the post-flowering period in all experiments, with the exception of experiment 1 where only the higher temperature range was used. In all cases, venting was triggered when the temperature rose 1°C above the set point temperatures.

Cold Storage

For all experiments, chill unit calculation was carried out based on the temperature-chill unit model for 'Elsanta' (Tehranifar, 1997) to allow quantification of chilling treatments. This model is the result of previous work determining the relationship between vegetative vigour, chilling duration and chilling temperature. It was developed using regression analysis on a combination of experiments testing the effects of chilling duration and chilling temperature on 'Elsanta's' vegetative growth. This analysis demonstrated that there is a curvilinear relationship between vegetative vigour and both chilling temperature and also chilling duration which can be accurately determined with a second degree polynomial (Tehranifar, 1997).

The model's upper limit of 14˚C was used as the ceiling chilling temperature after Kronenberg *et al.* (1976) demonstrated that this temperature does not chill effectively in strawberry. Regression analysis indicated that 2˚C gave the highest vegetative vigour, resulting in one hour at 2˚C being considered as one chill unit. Other temperatures had lower chill unit values as they diverged from this optimum chilling temperature.

Cold stores set to a constant temperature at the University of Reading were used in experiments 1 and 2 (Tasks 4.1 and 1.6 respectively), prior to planting. In experiment 3 (Task 4.5), a proportion of plants were placed in the University of Reading's cold stores and a proportion received field chilling. In these field chilling conditions, a grassy area approximately 6m by 12m at the School of Plant Sciences' Field Unit was surrounded by wind netting ('Residence' by TENAX, Wrexham, U.K.). The area was cleared of weeds and covered in black, nylon mulch matting ('Phormisol' 100g/m^2, Belgium) and a number of wooden slats placed on top, enabling improved drainage. The strawberry bags were positioned on top of the slats adjacent to one another. A sloping polythene-covered roof at a height of approximately 1.8m provided shelter from precipitation. This permitted the plants to be manually irrigated and avoided the potential problem of over-watering. All the bags were watered until saturation with mains water prior to being moved and grown on in the polytunnel. For cold storage at the University of Reading, the plants were placed in double-sheeted brown paper bags and stored in the dark.

Chilling temperatures in all experiments were recorded hourly by the use of Tinytalk II temperature loggers (RS components, Gemini Data Loggers, (UK) Ltd.).

Plant Material

The strawberry plants used in all the experiments were DEFRA certified stock of 'Elsanta'. Single crowned, A+ plants, with a crown diameter of 15mm or greater were used. In experiments 1 and 2, they were obtained from Darby Brothers Farms Ltd., Methwold, U.K., whilst in experiment 3, the plants were sourced from Edward Vinson Ltd., Faversham, U.K. All plants were field-grown and freshly lifted prior to delivery to the University of Reading.

Following cold storage, the plants were planted directly into 100cm (38 litre) strawberry bags containing a peat-based compost (Westland Horticulture, Dungallen, Belfast). The plants were evenly spaced at 20cm distance apart at a density of 10 plants per bag. In all experiments, 5 bags (50 plants) were used for recording yield for each treatment. Additional bags were used when destructive measurements during the course of the experiment were planned. The compost had a pH of 5.2 and for experiments 1 and 2 had an AFP of 9.1%. In experiment 3 the AFP was 15% ±1%. Holes were punched into the base of each of the growbags to assist drainage. Crowns were planted so that the centre of each crown was flush with the surface of the peat. The bags were watered to saturation immediately following planting and again a week later, on both occasions with mains water. Crown height was subsequently checked for position following watering.

Temperature Recording

Average air temperatures in all experiments were recorded using mounted K-type thermocouples connected to a Datataker DT-500 (Data Electronics, Cambridge, U.K.). The thermocouples were placed within an aspirated screen in the centre of the tunnel. In each case, temperature was measured every minute and hourly averages recorded.

Night-break Lighting and Blackout

Additional artificial lighting was used in experiment 3. The natural dark period was interrupted every hour for 15 minutes by low level incandescent lighting (45.3 µmols/m^2/sec) from 2100 HRS until 0500 HRS for 35d following chilling (Lieten, 1997). The lighting used incandescent, GLS clear bulbs (60W), fixed into bulb housings with internal reflectors and glass frontage, with an output of 9.0 $\mu mols^{-1}$ m^{-2} at 660nm (red light) and 14.4 $\mu mols^{-1}$ m^{-2} at 730nm (far red light), measured using a red to far-red meter (SKR 110/100-Skye Instruments Ltd., Powys, U.K.). Lights were positioned approximately 1m above plant height. The lights were mains powered and located approximately 1m apart directly above the middle of the benches. To enable segregation of lighting treatments, white-on-black polythene was raised and lowered every morning and evening respectively during the night-break lighting application. This prevented lighting of benches other than those intended.

Plant Hygiene

Prior to the start of each experiment, the benches and polytunnel interior were sprayed and washed down with Jeyes' disinfecting fluid (Jeyes' Ltd., Thetford, U.K.). Throughout all experiments, dead leaves and other waste material was removed from the plants and polytunnel interior, twice weekly.

Plant Nutrition

All plants were irrigated following planting with a liquid pre-fruiting feed (Table 1a and 1b) starting 3 weeks after planting using a Dosatron (Dosatron International, 33370 Tresses, France) to dilute the concentrated stock solution of feed. The bags were fed four to six times daily with the duration of each irrigation varying depending on prevailing environmental conditions. Accurate timed feeding periods were provided via an automated system (*Rainbird WTD –1900*, Field Fumigation Ltd., Appledore, England). Feed was supplied to the plants using irrigation piping and four pressure-compensated, integral dripper-spikes per bag (supplying 2 litres per

hour) (Netafim, Israel), placed equidistantly along each bag. In experiment 1, only two dripper-spikes were used per bag.

Table 33a. Basic feed solution used in all experiments. (Amounts to make up 100 litres of stock).

Compound	**Quantity**
Potassium Nitrate	3.0kg
Mono Potassium Phosphate	1.8kg
Magnesium Sulphate	2.0kg
Nitric Acid (67%)	2.7litres
Iron EDTA (13% Fe)	140g
Manganese Sulphate (32% Mn)	35g
Zinc Sulphate (23% Zn)	30g
Solubor (21% B)	14g
Copper Sulphate (25.5% Cu)	10g
Sodium Molybdate (40% Mo)	3g

Table 33b. The fertilizers supplied the following levels of nutrients in the feed (including contribution from mains water, concentrations in mg/litre).

Nitrogen	Phosphorus	Potassium	Magnesium	Calcium	Iron	EC ($mScm^{-1}$)
105	41	167	21	98	1.5	1.61

The feed was supplied at an electrical conductivity of 1.61 millisemens (mS), measured using a calibrated conductivity meter (Canterbury Scientific Instruments, Cambridge, U.K.) and a feed pH of 6.5 used, measured using a hand-held pH meter (Hanna Instruments, Bedfordshire, U.K.).20-25% feed run-off was maintained (Wilson, 1997) by monitoring the amount of feed supplied to the plants and the feed dripping through the bags. The electrical conductivity (EC) of the run-off was monitored weekly to ensure that the dilution equipment was working efficiently and the electrical conductivity did not rise within the bag (Wilson, 1997).

Pollination

At anthesis of the first flower, bumble bees (*Bombus impatiens* Cresson in *Total System Hive* – Novartis BCM Ltd., Colchester, England) were introduced into the polytunnel. The hives were replaced at 6 to 8 week intervals throughout flowering, in line with commercial practice (Wilson, 1997).

Pest and Disease Management

Biological controls were used wherever possible to control pests and diseases, although chemical sprays were also employed as necessary. Tables 2a and 2b show the chemical and biological controls used; these were applied as required and at the concentrations recommended by the manufacturer.

Table 34a. Biological controls used against pests and diseases.

Pest/ Disease	**Trade Name**	**Predator**
Aphid (*Chaetosiphon fragaefolii*)	Aphido-line (Novartis, BCM, Aldham, Colchester).	*Aphidoletes aphidimyza* 250/in ¼ litre bottle with vermiculite Application rate of ½ insect/m^2/week
Shallot aphid (*Myzus ascalonicus*)	Fightawing (Novartis, BCM, Aldham, Colchester).	*Chrysoperla carnea* 250/pack Application rate of 5-20 insects/m^2/week
Red Spider Mite (*Tetranychus urticae*)	Fightamite (Novartis, BCM, Aldham, Colchester).	*Phytoseiulus persimilis* 2000/vial with vermiculite 10-20 insects/m^2/week
White Fly (*Trialeurodes vaporariorum*)	Fightafly (Novartis, BCM, Aldham, Colchester).	*Encarsia formosa* 1500 supplied on cards ¾ - 1¼ insects/m^2/week

Table 34b. Chemical controls used against pests and diseases.

Pest or disease	Trade Name/active ingredient	Concentration
Aphid (*Chaetosiphon fragaefolii*)	Pirimor (Pirimicarb)	0.5g/l
Caterpillar (*Tortricidae* and *Noctuidae*)	Malathion (Organophosphorus)	40ml/l
Crown rot (*Phytophthora*)	Rovral (RP Agriculture) (Iprodione – 50% w/w)	1g/1l
Powdery Mildew (*Sphaerotheca macularis*)	Nimrod (Benlate (Benomyle) Sulphur	1.46ml/l Using burner – 4h/night
Red Spider Mite (*Tetranychus urticae*)	Torque (Agral (Alkyle phenol ethylene oxide))	3.5g/l
White fly	Savona (Soft soap)	49% w/w

Plant Growth Measurements

Plant measurements quantified the rate of plant growth during the initial part of the experiments. Petiole lengths were recorded from two randomly selected plants from each bag. The first three leaves to emerge from the crown after planting were measured every 10d, until the petiole length ceased to increase. The measurement was made from the top of the petiole/stipule union to the base of the centre leaflet (Tehranifar, 1997). Runners were counted and removed every 10 days. In experiments 2 and 3, plants were dissected and/or destructively sampled at specific stages of flower bud initiation, to quantify growth variation throughout the season (described below).

Fruit Harvesting

The time between planting and first pick was recorded for each treatment. Fruit were picked when >90% red and picking took place twice weekly. Fruit that were ripe were cut at the pedicel using scissors and placed in food-grade, aluminium small portion trays (Aro Products, Manchester, U.K.). Fruit weight and number were recorded for marketable and non-marketable berries (using the EC Specification, Regulation 899/87 annex II as amended by regulation 1435/91). Generally, fruit with a normal shape, a minimum shoulder diameter of 15mm and

weight greater than 5g were considered marketable. After picking, fruit were counted, graded and weighed. A Sartorius Model MCI balance (Eastleigh Instruments, Southampton) was used to weigh the fruit.

Destructive Sampling

Destructive sampling of the above-ground part of the plant was carried out by cutting the crown just above the last formed root initial. This was carried out on two plants per bag (chosen at random) at the end of the experiments. The leaves were removed and counted as was the number of crowns per plant. The fresh weight of the leaves, the crown weight, the number and weight of unripe fruit or flowers were also recorded for each plant. Leaf and crown dry weight was determined by drying each sample in a ventilated oven at 85°C for 5 days. The dry weight was then measured. Fresh and dry weight of the plant sections were recorded using a Sartorius Model MCI balance. Leaf area was measured using an area meter (Delta T Devices Ltd., Cambridge, U.K.). This area meter uses a video camera, projecting an image of the area to be measured onto a television screen. Accurate electronic scanning of this image allows irregular leaf margins to be measured. The instrument was calibrated before use on each occasion using regular shaped objects of known area. Leaf blades were placed between two clear Perspex sheets and flattened before measurement.

Dissections

The purpose of the dissections was to examine the floral status of the strawberry meristems microscopically, either prior to or as the flowers were emerging from the crown. The plants were dissected under a Wild Heerbrugg M3 Stereoscope (Heerbrugg, Switzerland), with a variable magnification of x9.6-60. Each consecutive leaf and stipule was removed until the meristem was revealed. The presence of flower primordia on the primary flower and a domed apex indicated whether the plant could be considered floral. The number of flowers could then be counted by removing them in succession. Durner and Poling (1985) attest that this is the most rapid and reliable method of determining the floral status of meristems in strawberry.

Statistical Analysis

Analysis of variance was calculated using the ANOVA procedure from the SAS statistical computer program (version 8.2). All means, standard errors and linear regression analyses were calculated using Microsoft Excel 2002 for Windows XP which was also used to produce graphs, tables and organise data.

Experiment 1. Determination of How Accumulated Chill Units Affect Cropping Period of the Cultivar Elsanta

Introduction

This experiment used controlled chilling to determine the effect on cropping period and yield of 'Elsanta'. Plants were cold-stored in November and chilled at a range of 3 temperatures and for 4 durations. The basic temperature-cropping response is known for 'Elsanta' and was used to calculate chill units during the course of the treatments. It was intended to clarify how the accumulation of chill units affects the cropping period, and to determine the extent of effect on marketable fruit quality and season extension.

Materials and Methods

Plants remained in the cold stores for four durations giving 12 treatments of 50 plants each (Table 35):

Table 35. The 12 experimental treatments (chilling temperature, chill units, duration and planting date).

Cold store temperature	Chill units	Number of days chilling	Planting date
2.4°C	1198	56	11-01-00
3.9°C	1162	56	11-01-00
7.9°C	899	56	11-01-00
2.4°C	1438	66	21-01-00
3.9°C	1395	66	21-01-00
7.9°C	1079	66	21-01-00
2.4°C	1678	76	31-01-00
3.9°C	1628	76	31-01-00
7.9°C	1259	76	31-01-00
2.4°C	1918	86	10-02-00
3.9°C	1860	86	10-02-00
7.9°C	1439	86	10-02-00

The polytunnel was maintained at a temperature between 15°C and 20°C over the experimental period. The first three leaves growing out from the crown were labeled in turn and their petioles measured at 10-day intervals. Runner number and time to flowering were also recorded. Fruit was picked and recorded twice weekly from each treatment. Destructive measurements were also carried out at the end of the experiment, in September 2000.

Results

For the benefits of clarity only three treatments are shown for the effects of chilling over the cropping period (899, 1395 and 1860 CU) (Figure 61). The first treatment to start cropping was the 1860 CU treatment (65 days). In contrast, the 899 CU treatment commenced cropping some 25 days later. Cropping duration was longer for those treatments receiving less chilling. Noticeably, the greatest single yield for any pick date occurred with the treatment receiving the least chilling (899 CU), with a mean yield of 52g per plant, some 121 days after planting. This was significantly different from the other treatments ($P<0.05$).

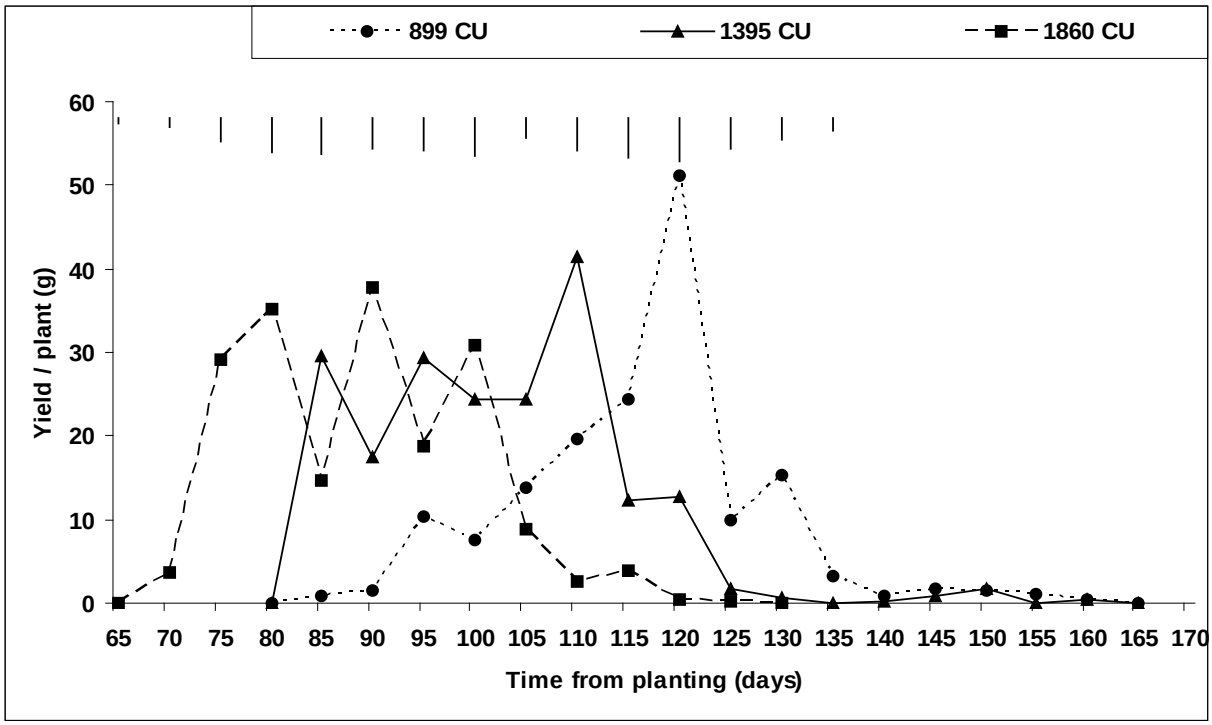


Figure 61. Total yield per plant over the cropping period for three representative treatments (CU = chill units). Standard errors of the difference between means are shown. (df = 48).

A significant relationship was observed between chilling and marketable yield (Figure 62). As chilling increased, mean marketable yield per plant increased (P<0.05). The highest marketable yield was produced at 1628 CU.

Petiole length increased as the amount of chilling increased, up to 1395 or 1438 CU (P<0.001) (Figure 63). Maximum mean petiole length was approximately 100mm for these two treatments. Further chilling caused the petiole lengths to decrease. Those chilling treatments which used the higher cold store temperature of 7.9°C (899, 1079, 1259 and 1439 CU) in general caused low mean petiole lengths when compared to the other treatments, although this was only statistically significant for the 1439 CU treatment.

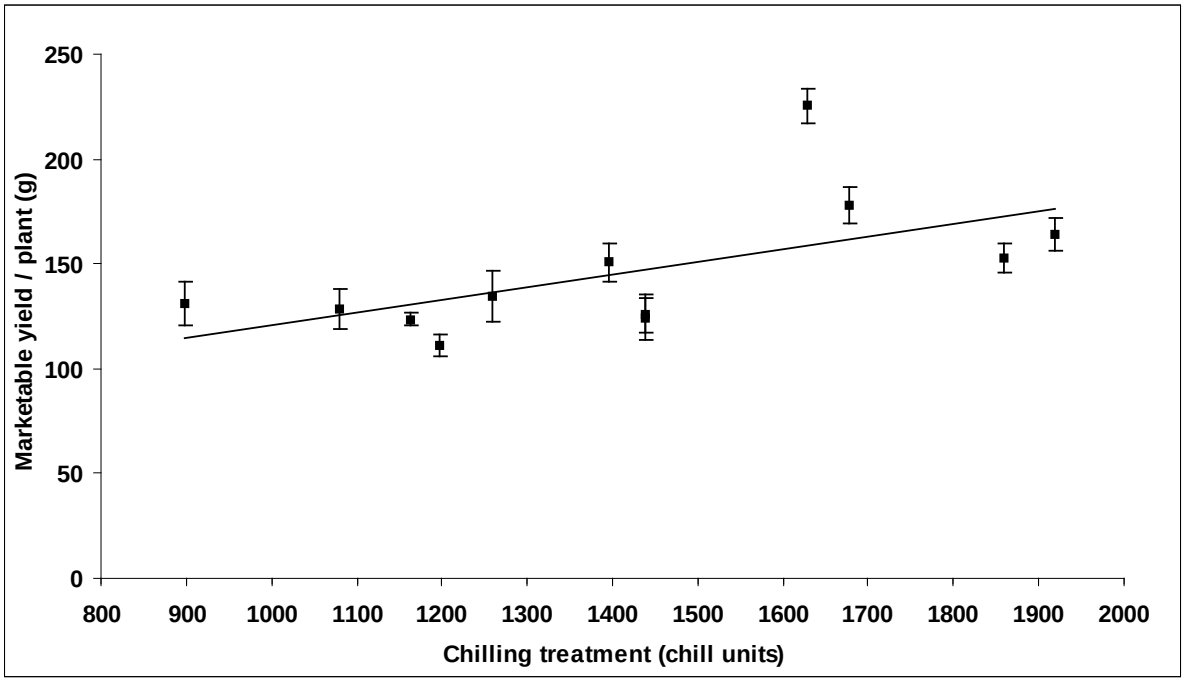


Figure 62. The effect of chilling treatment on the mean marketable yield per plant. The fitted relationship is of the form y = a + bx where a = 60.791 and b = -0.0602. Standard errors of the fitted parameters are 37.01162 and 0.02563. R^2 = 36%. Standard error bars are shown. (df = 48).

Over the course of the experiment, a proportion of plants died from some of the treatments. All of the treatments cold stored at 2.4°C ended the experiment with a full compliment of plants (Figure 64). However, plant losses were present both for plants cold stored at 3.9°C and especially those at 7.9°C (P<0.05). Indeed, only the 1395 CU (3.9°C) treatment did not lose any plants due to treatment effects. Chilling at 3.9°C resulted in a mean of 9.1 plants per bag surviving whilst at the highest temperature (7.9°C), a mean of only 6.2 plants per bag survived. The least number of surviving plants (4.2 per bag) was for the 1259 CU treatment, at the cold storage temperature of 7.9°C.

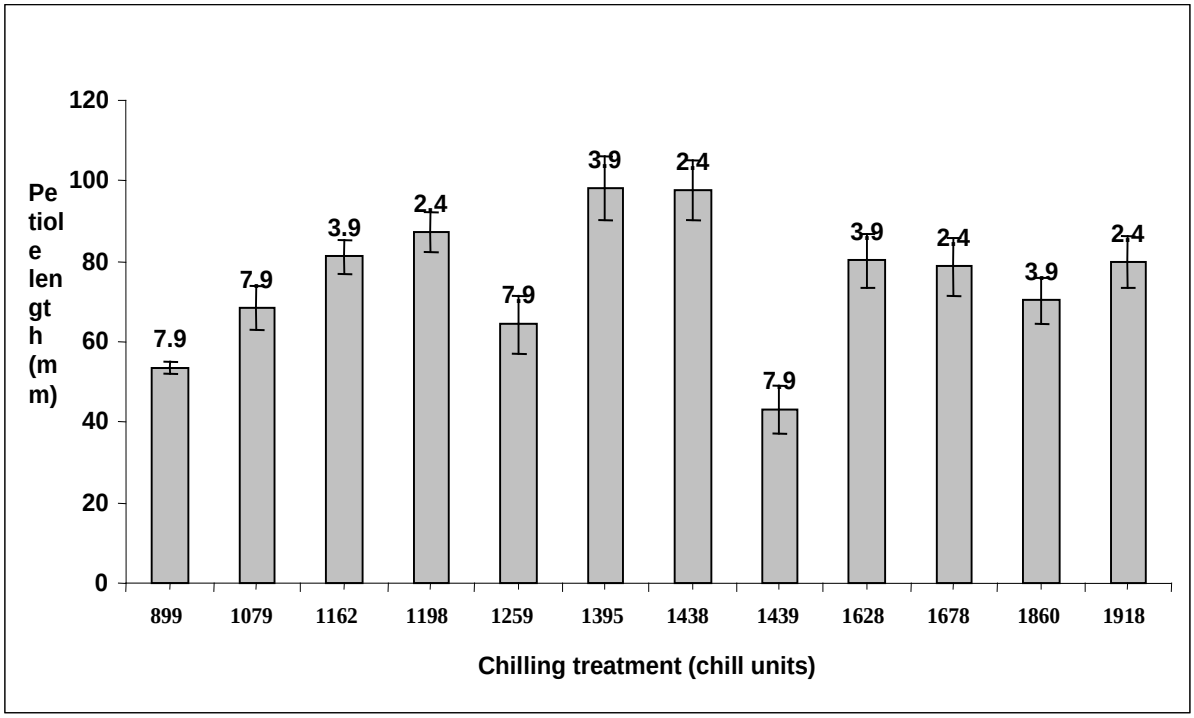


Figure 63. The effect of chilling treatment on the mean petiole length. Storage temperatures are shown for each of the chilling treatments (°C). Standard error bars are shown. (df = 48).

Experiment 1 Conclusions

- As chilling accumulation increases, the plants fruit earlier.
- Marketable yield increases with chilling up to ~1600 CU. [As a guide, plant yields increase approximately 4g for every 100 CU increases].
- Increased chilling first has a positive effect, followed by a negative effect (as the optimum is attained) on vegetative growth.
- Maximum petiole length (reflecting vegetative vigour) is found at 1300-1400 chill units, confirming previous work.
- Cold storage at too high a temperature leads to poor plant performance.

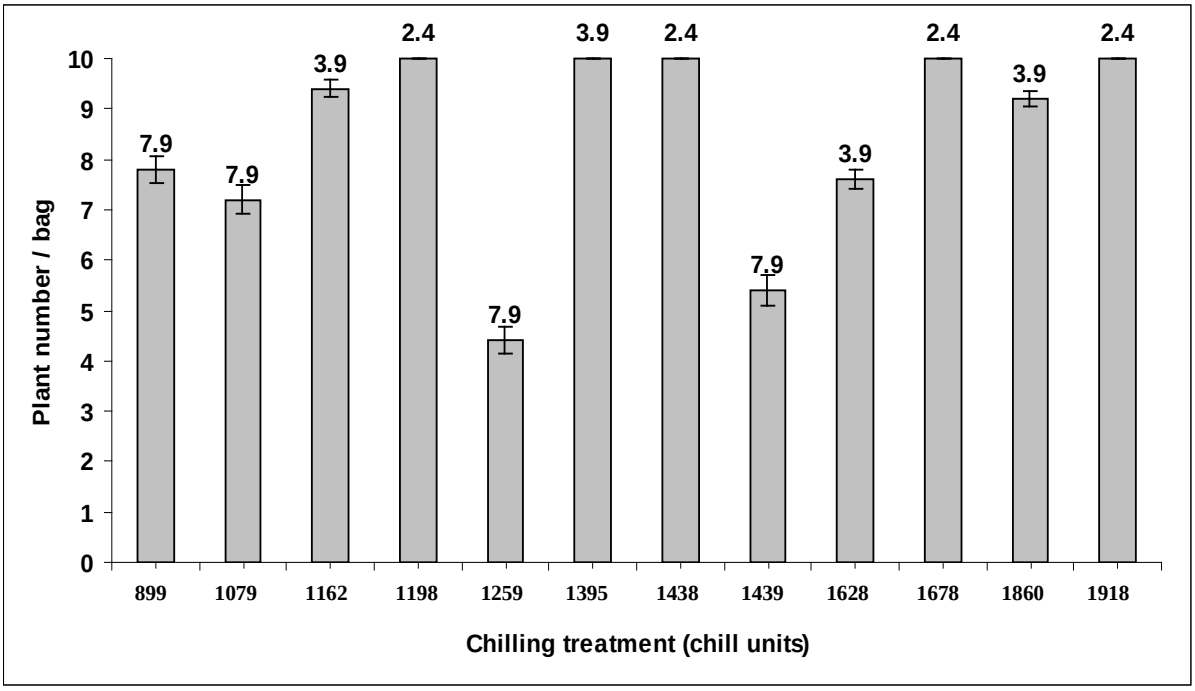


Figure 64. Mean number of plants per bag at the end of the experiment (September 2000). Storage temperatures are shown for each of the chilling treatments (°C). Standard error bars are shown. (df = 48).

Experiment 2. Determine the possibility of inducing two flowering periods to extend the cropping season

Introduction

This experiment examined the possibility of using the induction of two flowering periods in 'Elsanta' as a means of extending the cropping season and determined the effect of chilling on winter and spring flower initiation. Chilling is known to impart vigour to 'Elsanta' but it also induces a refractory period, during which further flower initiation cannot take place. Low temperatures (10 - 15 °C) and natural short-days were used in the winter and spring to test whether further flower initiation can occur, in addition to the autumn. In this way the duration of the refractory period was tested. Whether those flowers initiated in autumn affect this was tested by a pinching treatment (physical removal of autumn-initiated flowers).

Materials and Methods

On 27th October 2000, 720 plants were divided into five equal batches of 140 plants each and a batch of twenty plants for immediate dissection – see below. One batch of 140 plants was immediately planted into Westland strawberry bags and placed in the polytunnel. The other four batches were cold stored. Plants remained in the cold store for four durations. In this way five different chilling treatments were provided, chill units being calculated according to Tehranifar (1997).

To distinguish between those flowers that were initiated in spring and those initiated the previous autumn, a pinching regime was utilised. Using thumb and forefinger, flowers emerging from the crown in the 'pinched' treatments were manually removed and discarded, every seven days. A time of some 10 to 14 days after induction is known to occur before initiated flowers become visible in the crown by meristem dissection (D. Taylor, 2001; pers. comm.).

Following flower removal by pinching, a lack of further flower emergence from the crown for a minimum period of two weeks indicated that autumn-initiated flowers had fully appeared; any subsequent emerging flowers were deemed the result of winter-spring flower initiation. These subsequent flowers were then allowed to flower and fruit normally with no further flower removal for that particular plant. The assumption was that all pinching effectively removed all flowers initiated prior to the commencement of the experiment.

The set of plants for each chilling duration was divided equally into two pinching regimes (pinched and unpinched – see below) to give 10 treatments of 70 plants each (Table 36).

Table 36. The treatments (chilling duration and pinching regime).

0 Chill Units - Pinched	0 Chill Units - Un-pinched
500 Chill Units - Pinched	500 Chill Units - Un-pinched
1000 Chill Units - Pinched	1000 Chill Units - Un-pinched
1500 Chill Units - Pinched	1500 Chill Units - Un-pinched
2000 Chill Units - Pinched	2000 Chill Units - Un-pinched

Plant meristems were dissected under a dissecting microscope. This was carried out to determine the timing of secondary flower initiation and thus establish the duration of the refractory period. On plant receipt and before the plants were planted into growbags, 10 plants, selected at random, were dissected. Dissections were also conducted at eight weeks following planting out for each of the treatments by selecting a growbag (originally planted with 10 plants at the start of the experiment) at random.

Seventy plants (at a density of 10 plants per strawberry bag) were used for each treatment, with one bag being dissected at the 8 week dissection. Planned dissections at 16 weeks following planting could not be carried out, however, because of insufficient plant material. The bags containing plants to be dissected were selected at random from within the treatment.

As described in the general materials and methods the peat used in this experiment had an air-filled porosity (AFP) of 9.1%. This gave the growbags a tendency to retain moisture. This factor, coupled with the low chilling receipt of many of the treatments and a damp winter, led to a very high plant mortality rate in many of the treatments. Therefore, none of the pinched treatments were included in the dissection, in order to preserve the few plants left by spring for cropping analysis. Of the other treatments, 0 and 500 CU were not present in sufficient quantities to dissect, so that only the 1000, 1500 and 2000 CU unpinched treatments had their meristems dissected.

Results

Microscopic flower numbers per truss for the unpinched treatments of 1000 to 2000 CU and for fresh plants (as delivered) are shown in Figure 65. None of the 0 or 500 CU treatments were included in the dissections because of insufficient replicates. Dissections were carried out at 8 weeks following planting out of each treatment. Interestingly, primary flower number was greatest in the fresh plants and decreased with an increase in chilling ($P<0.05$) (from about 9.5 flowers when fresh to 5.5 flowers at 2000 CU). The greatest number of flowers found by dissection was in the 1000 CU treatment ($P<0.05$); this treatment also had the most tertiary flowers.

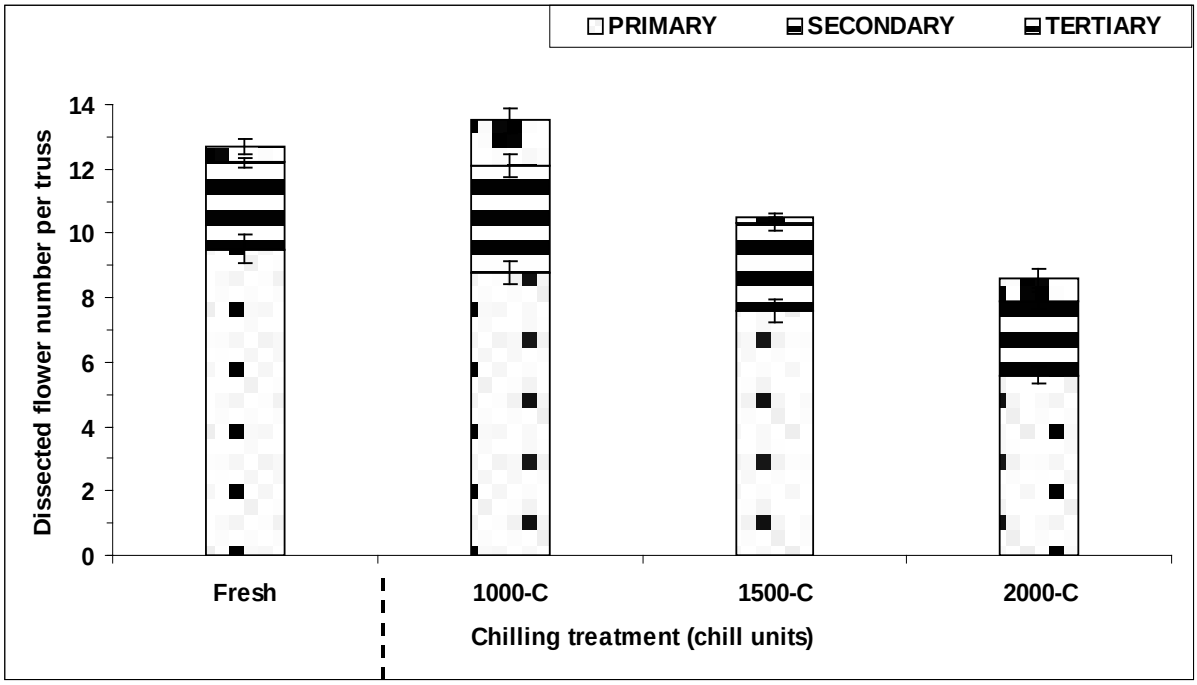


Figure 65. The effect of chilling treatment on the proportion of flowers per crown. Dissections were carried out 8 weeks after planting. Standard error bars are shown. (df = 56).

A lack of chilling caused a delay in the start of cropping (0 CU, 204 days after planting) (Figure 66). This contrasts with a cropping start at day 141 for 1500 CU of chilling. The 1000 CU treatment lay between these two extremes. The potential for cropping extension can be seen in the 1000 CU pinched treatment (arrowed). By day 220 the 1000 CU unpinched treatment had completed cropping; this was extended in the 1000 CU pinched treatment. The 1500 CU pinched

treatment had a minimal effect on prolonged cropping. This was probably due to the increased level of chilling, as the 2000 CU pinched treatment produced no further flowers or fruit.

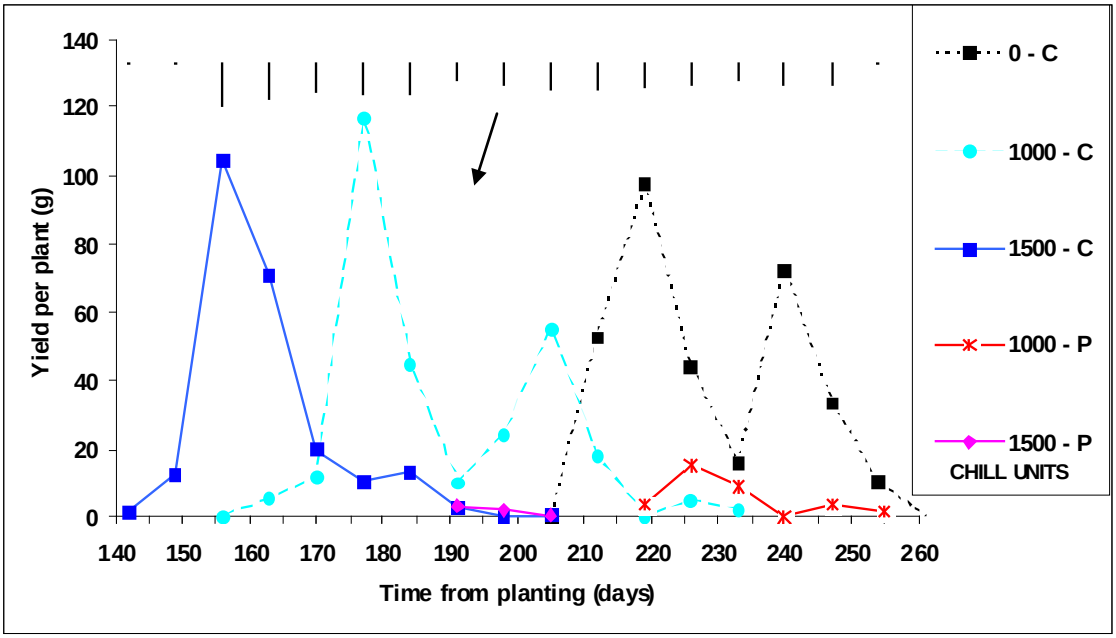


Figure 66. The effect of chilling treatment and pinching regime on the cropping profile (C = unpinched and P = pinched treatments). Standard errors of the difference between means are shown. Additional cropping resulting from secondary flower initiation is shown (arrowed). (df = 32).

The largest percentage of marketable fruit from the pinched treatments was produced with 2000 CU (P<0.05) (Figure 67). Indeed, of the pinched treatments, chilling over 1000 CU gave a greater marketable percentage per plant than obtained from unpinched plants receiving equivalent levels of chilling, although only the 1500 CU pinched treatment was significantly different from the 1500 CU unpinched treatment (P<0.05). The lowest percentage of marketable fruit was produced by the 500 CU unpinched treatment (44%) and this was significantly different from both the 0 and 2000 CU unpinched treatments (P<0.05).

Crown number per plant was greatest without chilling in the unpinched treatments (2.8 crowns per plant) (P<0.05) (Figure 68). An increase in chilling increased crown production in the pinched treatments, with the most crowns being produced in excess of 1000 CU (P<0.05).

Pinched plants produced significantly more crowns (4 crowns per plant at 2000 CU) than the similarly chilled unpinched treatments ($P<0.05$).

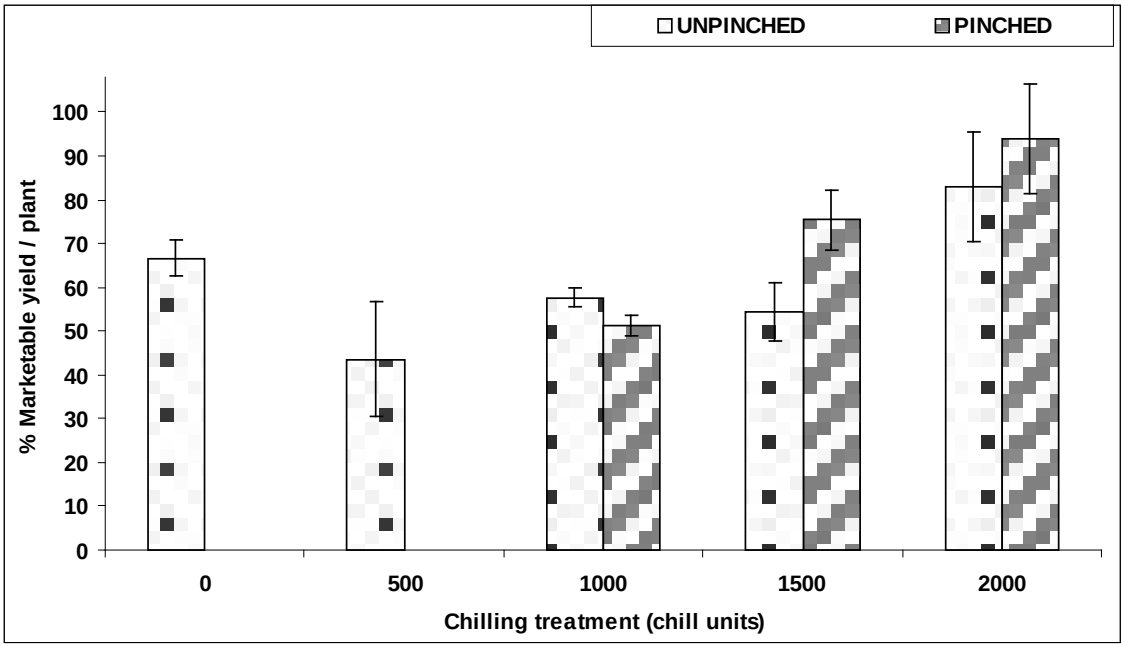


Figure 67. The effects of chilling treatment and pinching regime on % marketable fruit yield per plant. Standard error bars are shown. (Lsd = 18.22, df = 56).

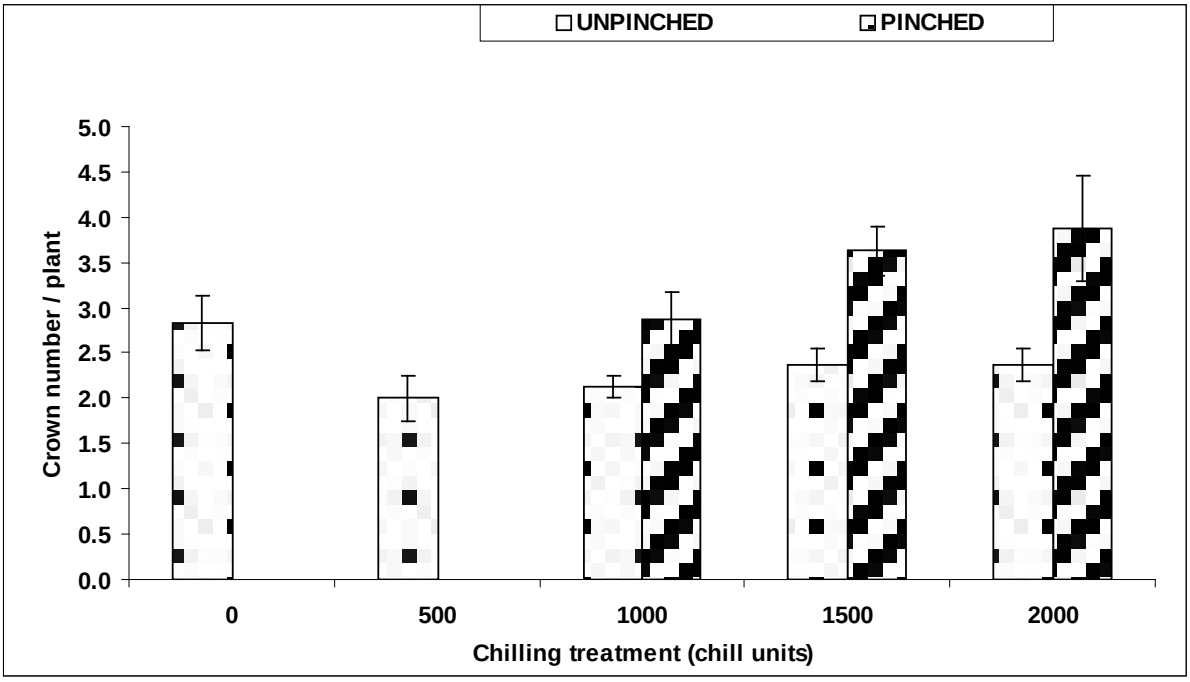


Figure 68. The effect of chilling treatment and pinching regime on crown number per plant. Standard error bars are shown. (Lsd = 0.25, df = 56).

Experiment 2 Conclusions

Increasing the level of cold store chilling:

- Reduces the possibility of secondary flower initiation (up to a maximum of 1500 chill units).
- Increases the duration of the refractory period.
- Decreases the cropping period.
- Increases the percentage of marketable fruit yield.
- In association with spring de-blossoming, increases vegetative growth and crown production to a greater extent than un-chilled plants.

Experiment 3. Exploring Alternative Methods of Supplying Optimum Chilling for Crop Quality

Introduction

This experiment used field chilling and night-break lighting to explore alternative methods of supplying optimum chilling for vegetative vigour, fruit quality and yield, whilst reducing the impact of the refractory period. During active growth over winter and spring, low temperatures (10 - 15 °C) and natural short-days were used to optimise secondary flower initiation. Samples were destructively harvested (and the meristem dissected) following night-break lighting, to record secondary flower initiation.

Materials and Methods

On 26th October 2001, 840 plants were delivered. Of these, 480 plants were immediately planted into Westland strawberry bags, 12 of which were placed in the polytunnel. The remaining 36 planted bags were positioned outside the polytunnel in a specially prepared plot to receive field chilling. A further 360 plants were placed into cold storage. The remaining 20 plants (which were selected at random) were dissected.

There were a total of 14 treatments of 60 plants each, composed of 4 chilling durations, 2 chilling methods and the application of night-break lighting following chilling (Table 37).

Table 37. The treatments (chill unit accumulation quantity and method, and the application of night-break lighting).

Chill units			Chilling type		Lighting application
0	CU	-	No chilling	-	Control
0	CU	-	No chilling	-	Night-break lighting
400	CU	-	Cold store chilling	-	Control
400	CU	-	Cold store chilling	-	Night-break lighting
400	CU	-	Field chilling	-	Control
400	CU	-	Field chilling	-	Night-break lighting
800	CU	-	Cold store chilling	-	Control
800	CU	-	Cold store chilling	-	Night-break lighting
800	CU	-	Field chilling	-	Control
800	CU	-	Field chilling	-	Night-break lighting
1200	CU	-	Cold store chilling	-	Control
1200	CU	-	Cold store chilling	-	Night-break lighting
1200	CU	-	Field chilling	-	Control
1200	CU	-	Field chilling	-	Night-break lighting

Night-break lighting was applied the day after the plants were transferred into the polytunnel. Plants were dissected as described in the general materials and methods. Samples were destructively harvested (and the meristem dissected) 7d following the end of night-break lighting, to determine the crown's floral status and provide evidence of secondary initiation. These data were related to resulting yields.

Results

Overall, plants receiving 800 CU yielded significantly more than the other chilling treatments, although this was not the case for cold store chilling without night-break lighting (Figure 69). Field chilling of 800 CU with night-break lighting optimised total yield (660g) although this was not significantly different from the same chilling treatment without night-break lighting (610g;

P>0.05). Cold store chilling of 1200 CU yielded significantly less fruit, producing the least mean fruit yield of all the treatments (350g per plant) (*P*<0.05). Night-break lighting and chilling type were very significant overall (*P*<0.01 and *P*<0.001 respectively).

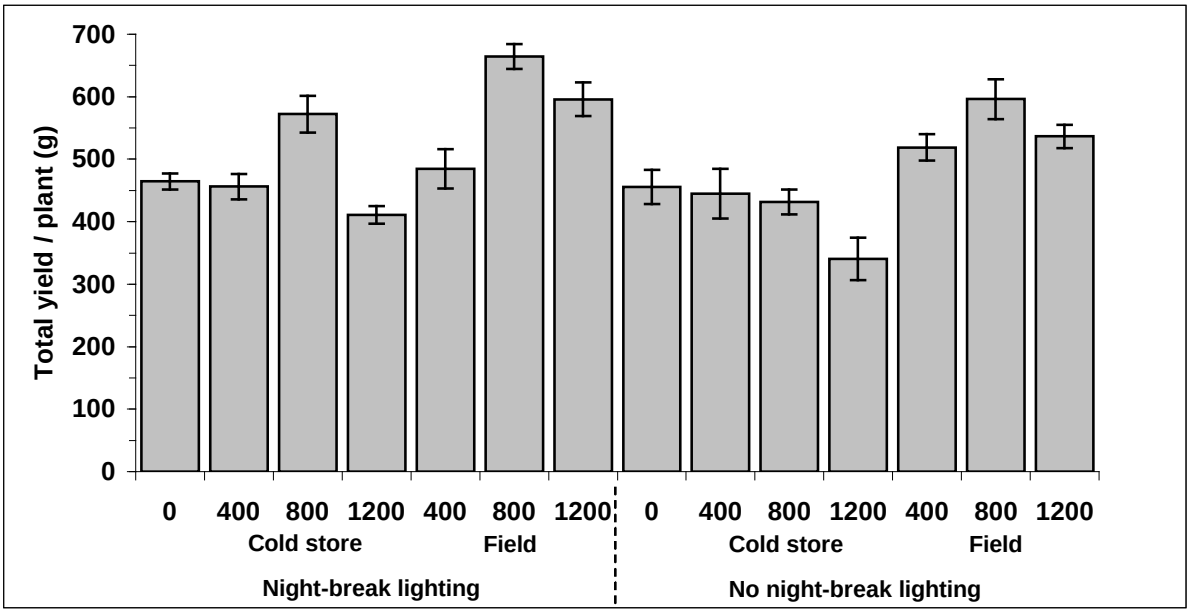


Figure 69. Mean total yield per plant (g), over the course of the experiment. Standard error bars are shown. Chill units are shown on the x-axis. (Lsd = 73.60, df = 56).

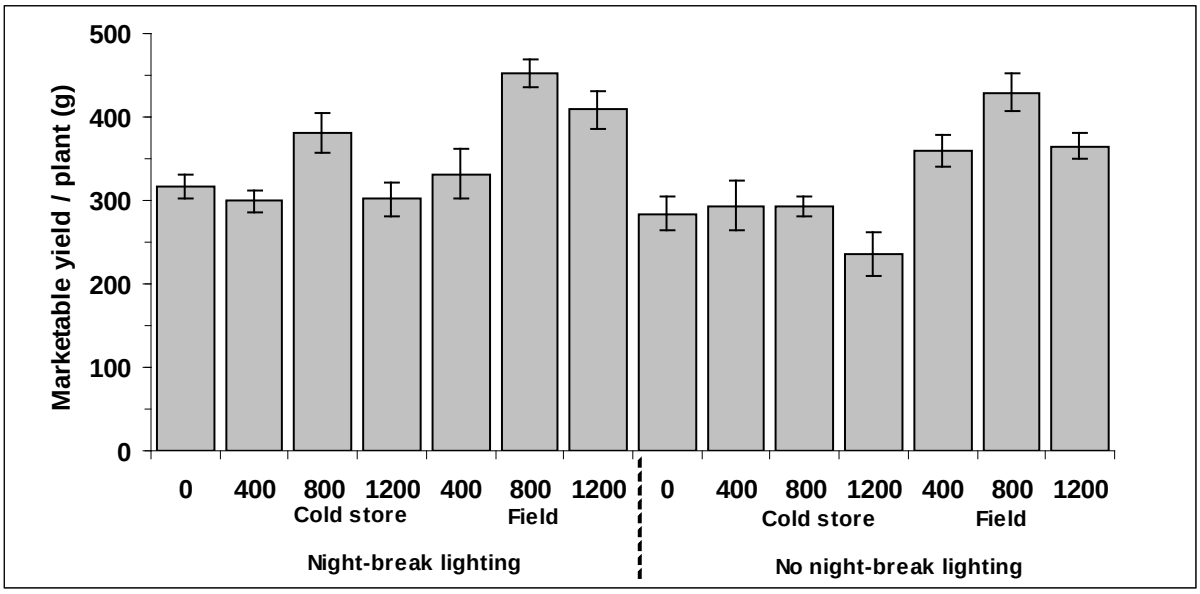


Figure 70. Mean total marketable yield per plant (g), over the course of the experiment. Standard error bars are shown. Chill units are shown on the x-axis. (Lsd = 59.74, df = 56).

As with total yield (Figure 69), plants that received chilling of 800 CU produced significantly more marketable fruit than the other treatments (P<0.05) (Figure 70). Field chilling of 800 CU with night-break lighting produced the most marketable fruit (450g) although this was not significantly different from the same chilling treatment without night-break lighting (P>0.05). As above, this was not the case for cold store chilling without night-break lighting. Cold store chilling at 1200 CU significantly decreased marketable yield (P<0.05). Night-break lighting had a significant beneficial effect overall on marketable fruit production (P<0.01).

The effect of night-break lighting on yield was more marked in those treatments receiving 1200 CU of cold store chilling (Figure 70). Initial yield was greater with lighting although this effect rapidly diminished. Initial cropping duration was considerably shorter with greater cold store chilling of 1200 CU (c.50 days) and this initial cropping period was especially marked in contrast to field chilling of 800 CU (c. 80 days). In further contrast to cold storage, where increased chilling decreased the time to first crop, plants in receipt of 800 CU field chilling started cropping almost simultaneously (for clarity, only the 800 CU field treatment is shown below) (Figure 71)

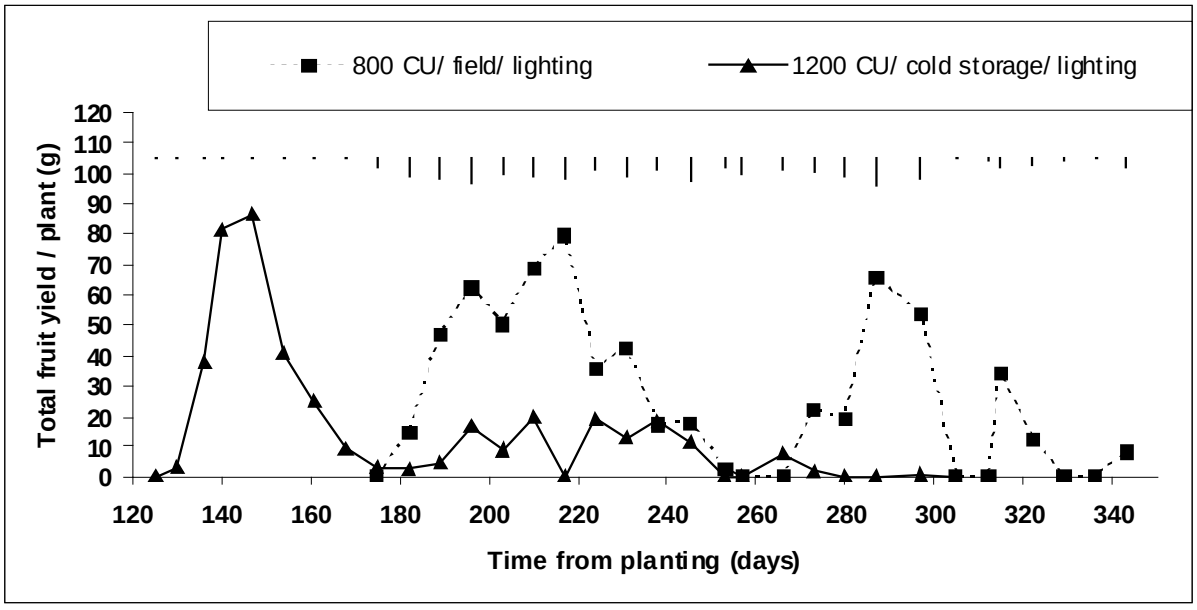


Figure 71. Total fruit yield (g) over the cropping period, with night-break lighting for both chilling types. Standard errors of the difference between means are shown. (df = 56).

Figure 71 shows mean total flower number per plant from dissections carried out in October 2001 (fresh plants) and October 2002 (treatments). There was no significant difference between the zero chill treatments (P>0.05), but these treatments had significantly more flowers than fresh plants (23 and 13 flowers, respectively) (P<0.05). Trend i (Figure 71) shows that although increased cold store chilling in the presence of night-break lighting resulted in an increase in total flower number, this was not the case for cold store chilling in the absence of night-break lighting (Figure 71, trend ii). Field chilling of 800 CU produced the most flowers, although this was not significantly different to the 400 or 1200 CU field chilling treatments (P>0.05).

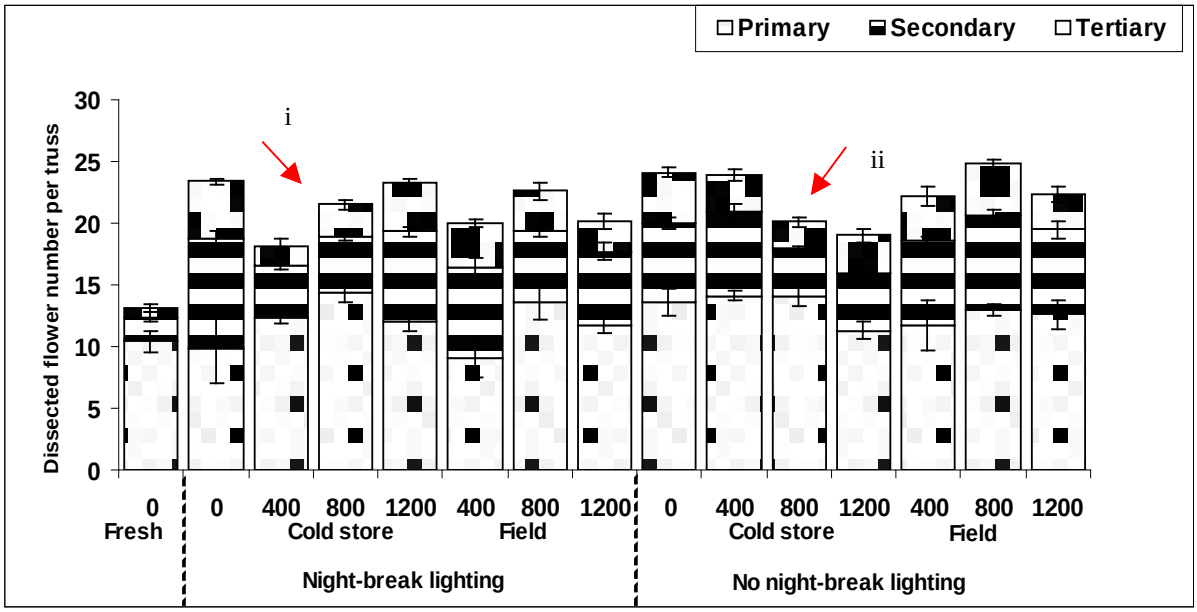


Figure 72. Total dissected flower number showing the proportion of flowers per crown both for fresh plants (as delivered) and following night-break lighting (various dates). Standard error bars are shown. Chill units are shown on the x-axis. (Lsd P = 3.46, S = 1.45, T = 1.42, df = 135).

The effect of chilling type and the interaction between chilling level and chilling type on the mean total runner number per plant during the experiment were significant (P<0.05 and P<0.001, respectively) (Figure 72). The zero chill treatment without lighting had fewer runners than those plants with lighting (5 and 9 runners respectively) (P<0.05). Cold storage of 800 and 1200 CU without lighting produced the greatest number of runners. In contrast, increased field chilling with night-break lighting resulted in a decreased runner number (P<0.05). There was no obvious

effect of field chilling without night-break lighting as the 800 CU treatment produced significantly more runners per plant than either the 400 or 1200 CU treatments (P<0.05).

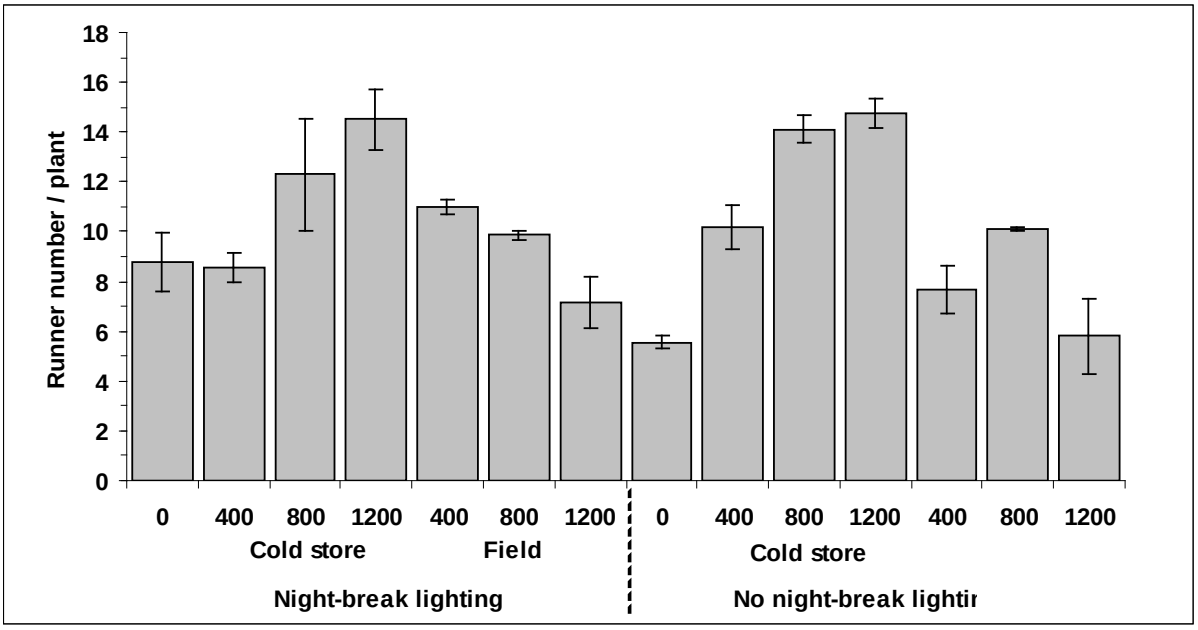


Figure 73. Total number of runners per plant over the course of the experiment. Standard error bars are shown. Chill units are shown on the x-axis. (Lsd = 2.91, df = 28).

Experiment 3 Conclusions

- The combination of field chilling of 800 CU and night-break lighting enabled secondary flower initiation to increase yields considerably (compared to the other treatments) to a mean of 660g/plant.
- Night-break lighting application significantly increased yield intensity during the initial cropping period.
- Night-break lighting did not affect the forcing period.
- Less chilling produced a more uniform cropping profile.
- For fruit production, field chilling was more efficient than cold store chilling, resulting in an optimum of 800 CU for marketable fruit production.
- Field chilling resulted in less vegetative growth than similarly cold-stored plants, thus potentially further enhancing yield potential.

- Greater secondary flower initiation (and therefore berry production) was possible under field chilling than for cold stored plants.

Discussion

The current commercial cold storage of strawberry runner plants prior to sale is a lost opportunity with A+ single crowned plants typically yielding 330g over a 45 days period. As a means of storage, cold storage is reliable and provides positive chilling effects, but the chilling received characteristically prevents further flower initiation during the otherwise ideal conditions of early spring. Once this chilling-induced refractory period is over, photoperiod has lengthened, temperatures risen above the critical 15°C and active growth commenced; further flower initiation is no longer possible.

Chilling provision in the field (a more efficient means of chilling than cold storage) enables flower initiation to continue following that occurring during autumn. Chilling restriction to 800 CU, measured using Tehranifar's (1997) chill unit model prior to forcing, promotes additional flower initiation with a temperature prior to anthesis of between 10 and 15°C. Night-break incandescent lighting after chilling did not inhibit flower initiation and had little effect on vegetative vigour, although fruit quality was optimised. A double-crop of 'Elsanta' resulted, yielding 660g/plant over an extended season of 160 days.

Larger plants are associated with larger yields, and waiting-bed plants typically yield 75% more than the A+, single-crowns used in this work (Wilson, 1997). A corresponding yield increase using the method described in this thesis cannot be assumed. However, it may be hypothesised that the system described here with larger, multi-crowned, Junebearing plants could easily produce Everbearer-like quantities of the preferred Junebearing fruit.

Overview

Yield increase and season extension have been shown to result from increased flower initiation (2001/2002 report). Whilst vegetative vigour and fruit quality were optimised with chilling, negligible flower initiation occurred with cold store chilling in excess of 1000 CU. Voth and

Bringhurst (1958) suggested an intermediate chilling state, with neither extremes of floral or vegetative growth in order to produce a satisfactory early crop. Clarification of a practical chilling method to promote the positive growth responses of plant and fruit quality without a refractory effect would, however, be a preferred method of supplying beneficial chilling effects.

Fruit yield was optimised with field chilling of 800 CU (producing 660g per plant) whilst the effect of night-break lighting was not statistically significant. This level and type of chilling with night-break lighting ensured a high yield of good quality fruit and a cropping period that extended from April to October, 2002.

Control of Flower Initiation

The Junebearing strawberry is a facultative short-day plant, with both flower initiation and runner formation being dependent on daylength and temperature (Darrow, 1936; Hartmann, 1947; Went, 1957; Ito and Saito, 1962; Heide, 1977; Guttridge, 1985). Night-break lighting had a negligible effect on flower initiation (daylength extension to 16h). This agrees with Darrow and Waldo (1934) who reported that *Fragaria* x *ananassa*, as short-day plants (SDP) require day lengths of 10h or less to initiate flowers at temperatures above 15°C; at lower temperatures (as in this experiment to anthesis), flowers could form under longer light periods. Sønsteby (1997) determined that flowers could be initiated independently of the number of inductive cycles below 15°C, whereas above this temperature, short-days were required for flower initiation. Konsin *et al.*, (2001) indicated that cv. 'Korona' was induced with a 13.5h photoperiod under 18°C whilst Durner *et al.* (1984) found that flowering was inhibited under night interruption and long-day conditions compared to short-day conditions, although flower initiation was possible under long-days (over 12h) at under 16°C (Guttridge, 1955; Hartman, 1947; Heide, 1977).

Although essentially a SDP, the Junebearing strawberry has been shown to be regulated by an inhibitory long-day process and hence may be more accurately described as a negative long-day plant (LDP) (Guttridge, 1985). Successful night interruption by Borthwick and Parker (1952) and the use of donor-receptor plants in long-day and short-day conditions (Guttridge, 1959a,

1959b) indicated that floral induction in Junebearers was favoured by a long, dark period rather than a short, light period.

Neither the mix of R and FR light nor the low R/FR ratio (0.61) of the incandescent lighting of this experiment inhibited flower initiation. This lack of effect may reflect a cultivar difference, with 'Elsanta' being less sensitive to light quality than other cultivars. It is suggested that sensitivity to temperature (Durner and Poling, 1988) caused an overriding, modifying effect, curtailing here the expected strong long-day effect, based on the findings of Vince-Prue and Guttridge (1973). A temperature-governing effect is not new, as reduced temperatures are known to modify the normal vegetative response to long photoperiods (Darrow, 1936; Hartmann, 1947; Voth and Bringhurst, 1958). Indeed, photoperiod is unlikely to have been the critical factor for flower initiation here, as the temperature to anthesis was below the 'critical level' of 15°C (Ito and Saito, 1962; Guttridge 1985).

In combination with increased cold store chilling, lighting produced an interesting contrary effect. Greater flower initiation occurred with lighting whilst the opposite occurred without lighting. In effect, lighting caused a reversal of the refractory effect of high chilling (1200 CU) although this was not so for field chilled plants.

Cold store chilling of 400 CU or less optimised secondary flower production, confirming both the potentially damaging effects of cold storage (Bringhurst *et al.,* 1960; Freeman and Pepin, 1971; Kinet *et al.,* 1993) and the increased refractory effect with increased chilling (Guttridge, 1960; Voth and Bringhurst, 1958) (Figure 52). Flower initiation occurred (as determined by meristem dissection) in the field chilling treatments, both with and without lighting, and was optimised at 800 CU. This suggests that lighting had little effect on the refractory period when chilling was field-supplied. A potentially different mechanism of chilling provision by field conditions is therefore indicated. A combination of continued growth in the field may have allowed more photosynthesis and additional assimilate storage, in contrast to the sterile, non-growth environment of the unlit cold store.

Yield Optimisation

Fruit quality has been shown to increase in proportion to cold store chilling (Figure 49). In partial contrast, field chilled plants produced significantly more marketable fruit than cold stored plants, although berries were smaller ($P<0.001$). Smaller fruit may have directly resulted from greater assimilate competition; a result of increased secondary flower initiation.

Surprisingly, Anderson and Guttridge (1975) found significantly increased yields without chilling, a negligible quantity of non-marketable fruit and an 'excellent' fruit quality overall. As here, however, in the absence of chilling or night-break lighting, Lieten (1997) found the resulting yield was poor. He also reported that following chilling accumulation, the use of night interruption improved fruit size and subsequent yield which, although indicated here, was not found to be significant ($P>0.05$).

Vegetative development especially that of branch crowns, has previously been associated with fruitfulness (Guttridge, 1985). However, a mean of 4 crowns per plant produced more fruit here than 8 crowns (800 CU field and 1200 CU cold store chilling).

Misshapen Fruit

Night-break lighting significantly reduced irregular fruit production overall (not a consequence of poor pollination) together with non-marketable and misshapen fruit numbers in the unchilled treatments. A lack of chilling has previously been associated with misshapen fruit (previous experiments) and this is consistent with these results. The production of significantly less poor fruit from field chilling, irrespective of pollination effects, is indicative of a preferred method of chilling, over the more standardised cold storage. It is suggested that the continued growth during secondary flower initiation permits meristem expansion thus reducing compaction of previously formed flower initials. Additionally, the highly significant effect of night-break lighting which obviously occurred after chilling receipt is suggestive of a vegetative elongation

effect overall. Alternatively, it is possible that the slow temperature reduction prevented 'frost shock'.

Low light intensity, temperatures under 17°C and inadequate chilling have been reported as primary reasons for inferior pollen production (Voyiatzis and Paraskevopoulou-Paroussi, 2002). This may lead to reduced fruit set and misshapen fruit from stamen sterility and poor pollen quality (Kronenberg, 1959; Kronenberg *et al.*, 1959; Gilbert and Breen, 1986). In agreement with the findings from this experiment, Lieten (1994) found that long-day conditions improved pollen quality and overall productivity.

Cold store and field chilling influenced the production of non-marketable fruit in completely opposite ways. Increased cold storage reduced poor fruit production in agreement with previous experiments whereas greater field chilling increased it. This may have resulted from the diurnal nature of field chilling and its extended duration; both might be expected to increase flower damage, leading to an increase in non-marketable fruit (Risser, 1997).

Season Eextension

Night-break lighting had no effect on crop duration although it significantly affected the total and marketable yield. This was especially apparent during the initial cropping period suggesting a photoperiodic effect on fruiting vigour. In the absence of lighting, total and marketable yield profiles were more uniform and less pronounced over the cropping period. Night-break lighting therefore appeared to mimic chilling effects, as peaks of production were visibly enhanced where lighting had been given.

As in experiments 1 and 2 (2000/1 and 2001/2), increased cold storage chilling had a negative relationship to the forcing period and overall crop duration, although no significant relationship was found ($P>0.05$). Greater chilling (as with night-break lighting) concentrated fruit production into a brief harvest, in agreement with Voth and Bringhurst (1958) working with cv. 'Lassen'. The clear relationship between increased cold storage duration and decreased time to first crop, contrasted with field chilling, where plants receiving less than 1200 CU field chilling cropped

almost simultaneously (the 1200 CU treatment only 7 days earlier, in contrast to a 31 day difference for 400 and 1200 CU of cold store chilling). Further, less field chilling produced a less marked, more extended cropping profile which could be attributed to the alternative nature of chilling receipt. Higher chilling levels from both chilling types resulted in more concentrated cropping periods.

Main-crop intensity was proportional to chilling and more pronounced with cold stored plants, a likely reflection of a strong physiological response to increased chilling, mirroring the shorter forcing period. In contrast, unchilled plants yielded less initially (main-crop) but cropped more intensely for the second harvest suggesting a lack of fruiting vigour (a result of insufficient chilling) and a slower emergence from true dormancy (Jonkers, 1965; Heide, 1977). While the remontant 'Redgauntlet' generally produces two fruit flushes over summer, Anderson and Guttridge (1975) reported that without chilling, both truss initiation and secondary cropping were advanced and increased.

The extended cropping period and less intense harvesting with reduced chilling agrees with the results of Voth and Bringhurst (1958) who compared a lack of winter chilling in deciduous fruit trees to similarly little definition in peaks of production. As here, these authors found that semi-continuous summer fruiting was clearly associated with a lack of chilling. In a later paper, Voth and Bringhurst (1970) determined that photoperiod was important in controlling the reproductive response since duration of the fruiting period was 'directly associated' with the length of time the plant had grown under short-days.

Conclusions

It is clear that the combination of field chilling of 800 CU and night-break lighting of 35 days enabled secondary flower initiation to increase yield considerably and allowed cropping period extension.

Night-break lighting significantly increased the yield intensity of initial cropping although it did not alter time to first crop. Overall, less chilling produced a more uniform cropping profile,

whilst greater chilling (especially that given in cold storage) resulted in a greater yield initially with less produced subsequently.

The provision of field chilling had considerable benefits compared to cold storage. Field chilling produced more berries overall (the result of greater flower initiation), with marketable fruit being optimised at 800 CU in contrast to the greater cold storage chilling previously found to be necessary. Significantly fewer runners were produced with field chilling (runner number actually decreased when it was given in combination with night-break lighting) and lighter, smaller leaves resulted, increasing the yield potential; this was probably a result of antagonism between fruiting and vegetative growth.

Recommendations

- Maximise yield and marketable quality in 'Elsanta' with 800 CU of field chilling and 35 days of incandescent, night-break lighting (15 min every hour from 2100 – 0500).
- Cold storage chilling of 'Elsanta' inhibits secondary flower initiation, and hence limits the cropping duration.
- Cold storage chilling at temperatures above 3.9°C cannot be recommended, as plant health suffers and plant performance deteriorates.

Determine the Effects of Chilling on Everbearer Plant Performance

Introduction

The effect of low temperatures (≤ 10 ^{o}C), or 'chilling', on flowering in JB cultivars is well established, with inhibition, reduction, or delay in further flower induction (Guttridge, 1985). In everbearer cultivars, the situation is less clear cut. Some work has showed that there were similar effects of chilling in everbearers (Smeets, 1982), whereas other workers report little effect of chilling on flowering (Yanagi and Oda, 1989; 1990; 1992; 1993). Chilling duration and intensity have been found to influence both the timing and duration of cropping in JB cultivars (Battey, *et al*., 1998), but it is not known whether similar effects occur in everbearer cultivars. The aim of this work is then to determine what the chilling requirements are for everbearers in general, and

in particular, for the cultivar 'Everest' (see experiments 2 and 3). More specifically this involves determining the most appropriate chilling temperatures, and their duration, to maximise cropping, and to relate these observations to current industry practice.

General Methodology

Cropping and Fruit Quality (all experiments)

For each of experiments 1, 2 and 3 a second set of plants was used for weekly records of crop quality and weight. Ten single-plant replications were used for each treatment, arranged in a randomised block design. Crop production was assessed by picking ripe fruit at least two days per week; during maximum fruit production fruit were sampled three times a week. Fruit collected was assigned to one of four classes (>35mm; 25-35mm; class 2 <22 mm; and unmarketable waste) depending on size (diameter). The former two classes (>35mm and 25-35mm) constitute commercial class 1 fruit. Individual cropping records were kept for each plant within the cropping trial and for each sampling date the total number and weight of fruit within each size class was recorded. For the purpose of this report, the cropping records have been summed for set periods of the growing season, which match the intervals between destructive sampling of plant dry weights. This enables the amount of crop produced to be related to the dry matter production of the plant over the same time period.

Chilling and Fruit Production Environments (experiments 2 and 3)

Detailed climatic records were taken throughout the experiment, including monitoring of the cold stores in which plants were chilled. Records taken in the polytunnel, for the commercial pre-cropping treatment, i.e. 'polytunnel control', show that plants were exposed to sub-zero temperatures for at least 22 nights. The cropping season air temperatures show that early season temperatures in April and May were around 15^{o}C. As the season progressed, the mean increased into the 20's and, in late July, maximum temperatures over 30^{0}C were recorded. By September the air temperatures had returned to around 15^{o}C.

Climate Records and Pollination (all experiments)

Temperatures of both the ambient air in the tunnel and in the pots/compost, together with light intensity, were recorded with a data-logger (Delta-T; Delta-T Devices Ltd, Burwell, Cambridge) throughout the duration of the experiment. Flowers were initially pollinated by hand using a small paint brush and then subsequently with the aid of bumblebees (Biobest "mini-hive"; BCP Ltd, Wye, Ashford, Kent).

Experiment 1. Determination of the Chilling Requirements of the Cultivar Bolero

Materials and Methods

Plant Material

Plants of Bolero were obtained from a commercial propagator (Hargreaves Plants Ltd., Brook House Farm, Gedney Dyke, Spalding, Lincolnshire.) in December 1999 and grown on in a glasshouse. Starting in January 2000, five batches of plants were transferred, at two-week intervals, to a cold store at $+2^{o}$C. These transfers were timed so that 2, 4, 6, 8 and 10-week chilling treatments ($+2^{o}$C) were achieved. A control batch (no chilling) of plants was maintained in the glasshouse throughout. At the end of the chilling treatments early April, all plants were transferred to a polythene/gauze tunnel for cropping. The plants were potted up into 2 litre pots using the standard peat compost (Professional Potting Compost, Westland Horticulture).

The plants were grown as a double row, on an elevated (1m high x 0.47m wide) bench supporting system. Plants were watered and fed via a drip irrigation/fertigation system, with one dripper (2 litres per hour) per pot. Initially after repotting, plants were supplied with water only; on 25th April, feeding commenced using a proprietary water soluble fertiliser (Agrasol 'F' 313; Scotts UK Professional, Bramford, Ipswich, IP8 4BZ). This was injected into the irrigation water via a proportional diluter ('Dosatron' model DI16; Dosatron International, France) to give a conductivity of 1-1.2 mScm^{-1}. In mid-May (when plants had commenced fruiting) the feed was changed to Agrasol'F' 316, and conductivity of diluted feed increased to 1.3-1.7 mScm^{-1}. Once a week, plants were thoroughly flushed through using water only. Plants were watered/fed up to

six times in a 24hr period, depending on their development and weather conditions. The duration and frequency of irrigation was controlled by means of a manually adjusted solenoid valve/timer (Gardena 1060; Erin-Gardena Ltd, Letchworth Garden City, Herts.). A regime of fungicide and insecticide sprays was used as necessary, together with biological control measures.

Experimental Design

The experiment was conducted using a randomised block design, with 12 replications of two-plant plots for each of the six chilling treatments as follows:

1. control in a glasshouse
2. 2 weeks at +2^{o}C
3. 4 weeks at +2^{o}C
4. 6 weeks at +2^{o}C
5. 8 weeks at +2^{o}C
6. 10 weeks at +2^{o}C

In addition, a further set of plants was grown for destructive sampling. Starting in early April 2000, six plants from each treatment were sampled at approximately 4-week intervals until the final sampling at the end of August.

Results

Distribution of Plant Dry Matter

Dry matter determined at sampling 1 in early April suggested that there was a trend for plant mass, irrespective of plant part (roots, crowns, petioles, laminas and truss), to decline with the length of the chilling period (Figure 74). These trends were statistically significant with respect to the chilling treatment for roots (P=0.004), crowns (P<0.001), petioles (P<0.001) and laminas (P<0.001), but not for truss weight. Significant trends were also evident with leaf number per plant (P=0.025), mean individual leaf area (P<0.001) and total leaf area per plant (P<0.001) (Figure 76).

For the second sampling, on the 2 May, there was a marked decline in dry matter associated with the length of the chilling period (Figure 74). Roots and laminas from the no chill and 2 week

duration chill treatments were larger than in the first sampling. These treatment trends were highly significant (*P*<0.001*)* for roots, crowns, petioles, laminas and truss weights. As evident with the first sampling, similar significant trends were also evident with leaf number per plant (*P*<0.001), mean individual leaf area (*P*=0.035) and total leaf area per plant (*P*<0.001) (Figure 76).

At the third sampling on the 5 June, treatment differences in dry weights were less marked for the no chill through to the 6-week chill treatment (Figure 74). Analysis did show that significant treatment differences were still evident for roots (*P*=0.006), crowns (*P*<0.001), petioles (*P*=0.003), laminas (*P*<0.001*)* and truss dry weights (*P*=0.002). Total leaf area and leaf number per plant were also significantly different as with earlier samplings (*P*<0.001*),* but mean individual leaf area was not (*P*=0.097) (Figure 76).

With the exception of truss dry weight, at the fourth sampling (28 June), there were no significant treatment differences for any plant part (Figure 75). Truss dry weight declined (P<0.001) by more than 50% with length of chilling, comparing the no chill with the 10 week chilling treatment. Leaf number per plant showed a significant difference (P=0.005), declining from 54 for the no chill treatment to 38 leaves per plant for the 10 week chilled treatment (Figure 76).

At the fifth sampling, on 24 July, there were no significant treatment differences with respect to dry matter partitioning to any plant part (Figure 75). There were also no treatment differences with respect to mean leaf area, number of leaves per plant, or total leaf area per plant.

At the final sampling (29 August) there were significant treatment differences in crown (P=0.027), petiole (P<0.001), lamina (P<0.001) and truss dry weights (P=0.032) (Figure 75). There were also significant treatments differences in leaf number (P<0.001) and total leaf area per plant (P<0.001), but not mean leaf area (P=0.497) (Figure 76). It remains unclear why treatment differences should reappear at the end of the growing season, but it is possible that plants which received less chilling remain in a productive state (vegetative and reproductive) longer compared to those plants which were chilled for longer.

Fruit Production During the Cropping Trial

Picking commenced at the end of May and was terminated at the end of August for all treatments. The total weekly production of fruit recorded for each treatment, within each size class units yield per treatment separately and for total yield is shown in Figures 77 and 78. Plants having received no chilling produced fruit in relatively consistent cycles over the whole cropping period. The pattern of cropping for plants having received increasing amounts of chilling, showed a trend for a reduction in fruit production early in the season, a pronounced reduction in mid-July, and a significant increase in the latter part of the season. Total cumulative yields recorded over the cropping period were as follows (all g/plant): 0 chilling – 652; 2 week chilling – 579; 4 week chilling – 398; 6 week chilling – 441; 8 week chilling – 347; 10 week chilling – 313. There was a clear trend for increased chilling reducing yields overall, as well as effecting the cropping pattern. Despite the no chill treatment producing the greatest amount of class 1 fruit, it also had the highest amount of rots. For most treatments, the initial fruit cumulative pick rate was high. For the no chill treatment it began to decline by day 200 (19 July). In the other treatments however, the decline began progressively earlier, i.e. around day 166 for 10 weeks of chill.

Discussion

The results obtained with the treatments applied to 'Bolero' clearly show a significant negative effect of chilling on shoot and root growth. This was apparent, both during the treatment period itself and as a "carry over" effect for a significant period during subsequent development after chilling treatments had finished. However, an important consideration to be taken into account is the method used to apply the chilling treatments i.e. in the dark at 2°C. Thus, there was the confounding factor of light, or lack of it, in addition to the number of chilling units the plants received, that will have influenced plant and root growth through the effect on photosynthate production and supply.

The influence of chilling on the pattern of flower and fruit production produced a clear reduction in fruiting approximately 100 days after the completion of the chilling treatments. The initial fruiting period will have been the result of flowers that were initiated prior to chilling. Since the

period between flower initiation and ripening of the resulting fruit is thought to be between 80 – 132 days, depending on temperature (Guttridge, 1985), the results would suggest that chilling inhibited, reduced, or delayed further flower induction in 'Bolero', as has been reported for other cultivars (Guttridge, 1985). Although this effect has been found with some Everbearer cultivars (Smeets, 1982), contradictory results with other everbearers have also been reported (Yanagi and Oda, 1989, 1990, 1992, 1993), where chilling was found to have little or no effect on flowering.

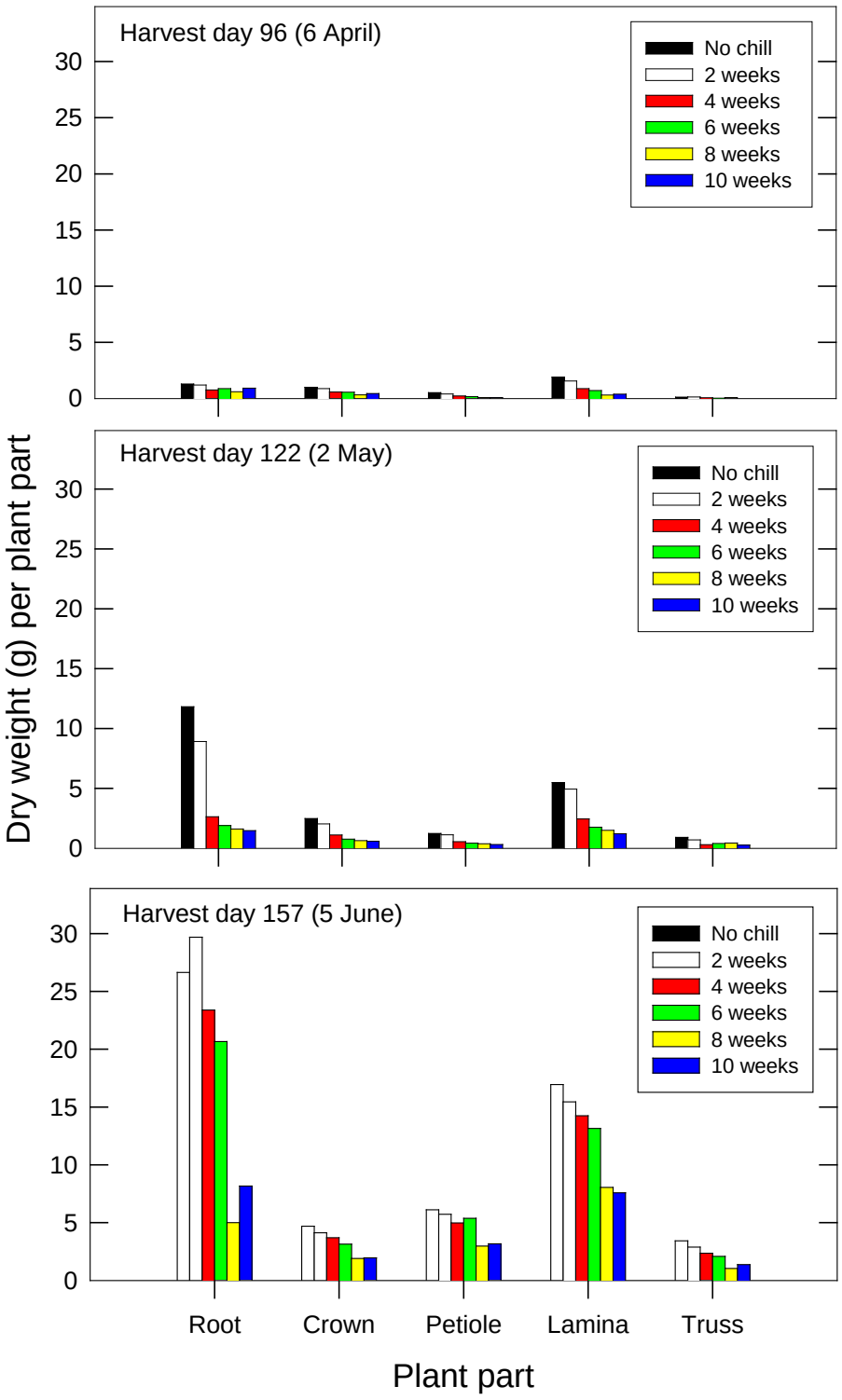


Figure 74. Dry matter distribution to various parts (root, crown, petiole, lamina and truss) of 'Bolero' plants, sampled on 3 dates, subject to five chilling treatments of different length.

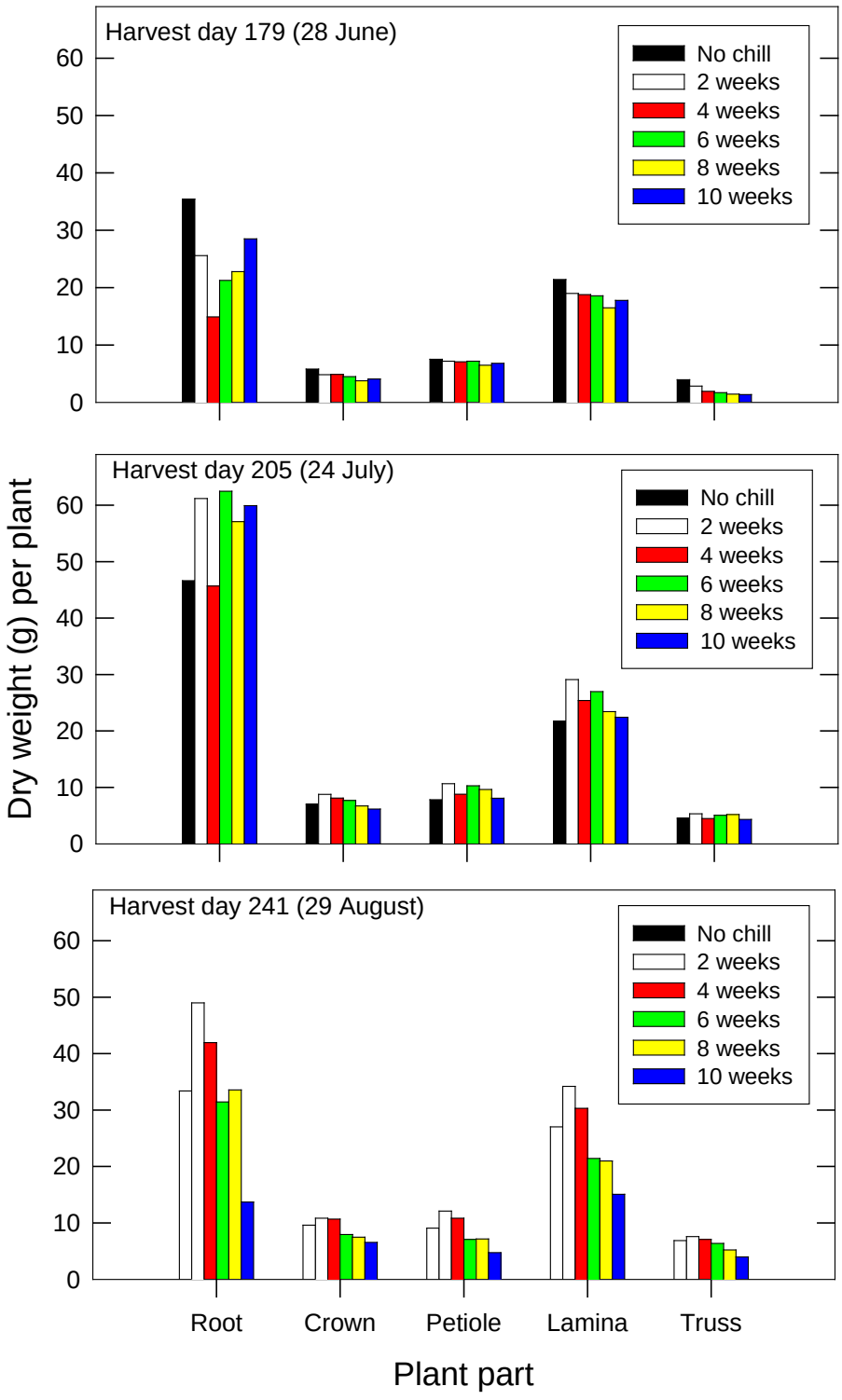


Figure 75. Dry matter distribution to various parts (root, crown, petiole, lamina and truss) of 'Bolero' plants, sampled on 3 dates, subject to five chilling treatments of different length.

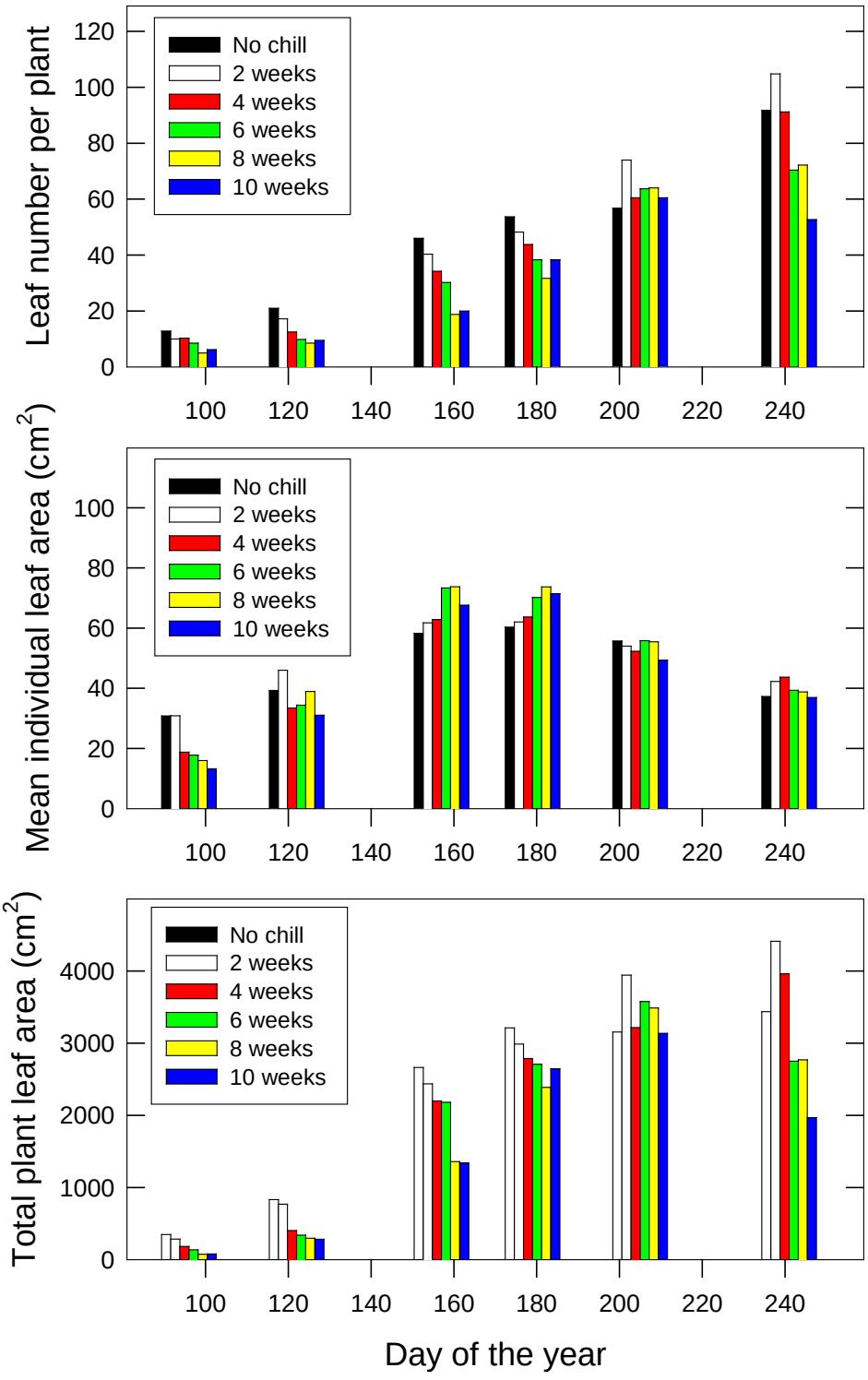


Figure 76. The leaf number, individual mean leaf area and total leaf area per plant for 'Bolero' plants at sampled on 30 March and subject to five chilling treatments of different length.

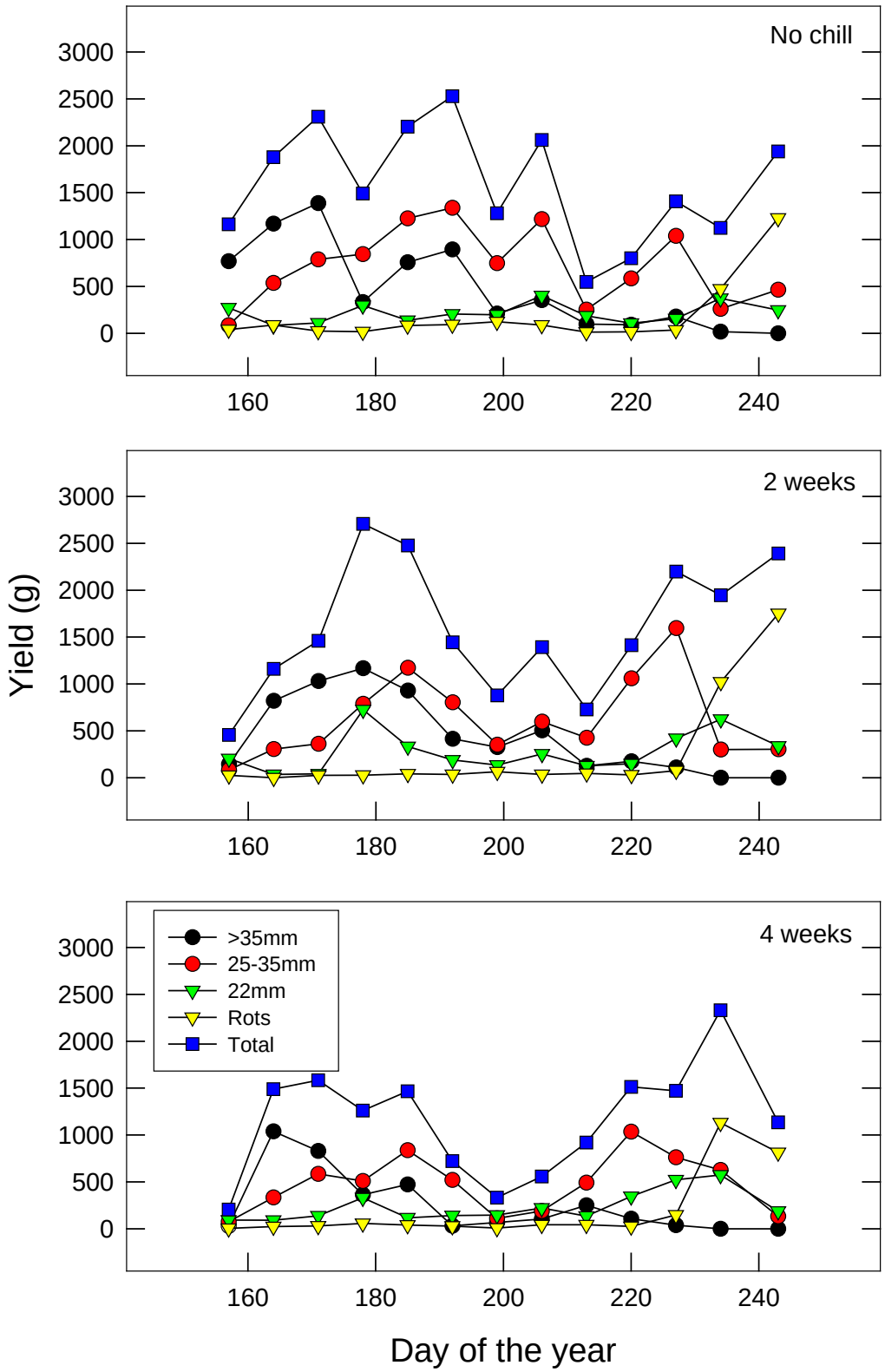


Figure 77. Effect of three chilling treatments on the weekly yields and grade-out of 'Bolero'. Top – no chilling; middle – 2 weeks chilling; bottom – 4 weeks chilling.

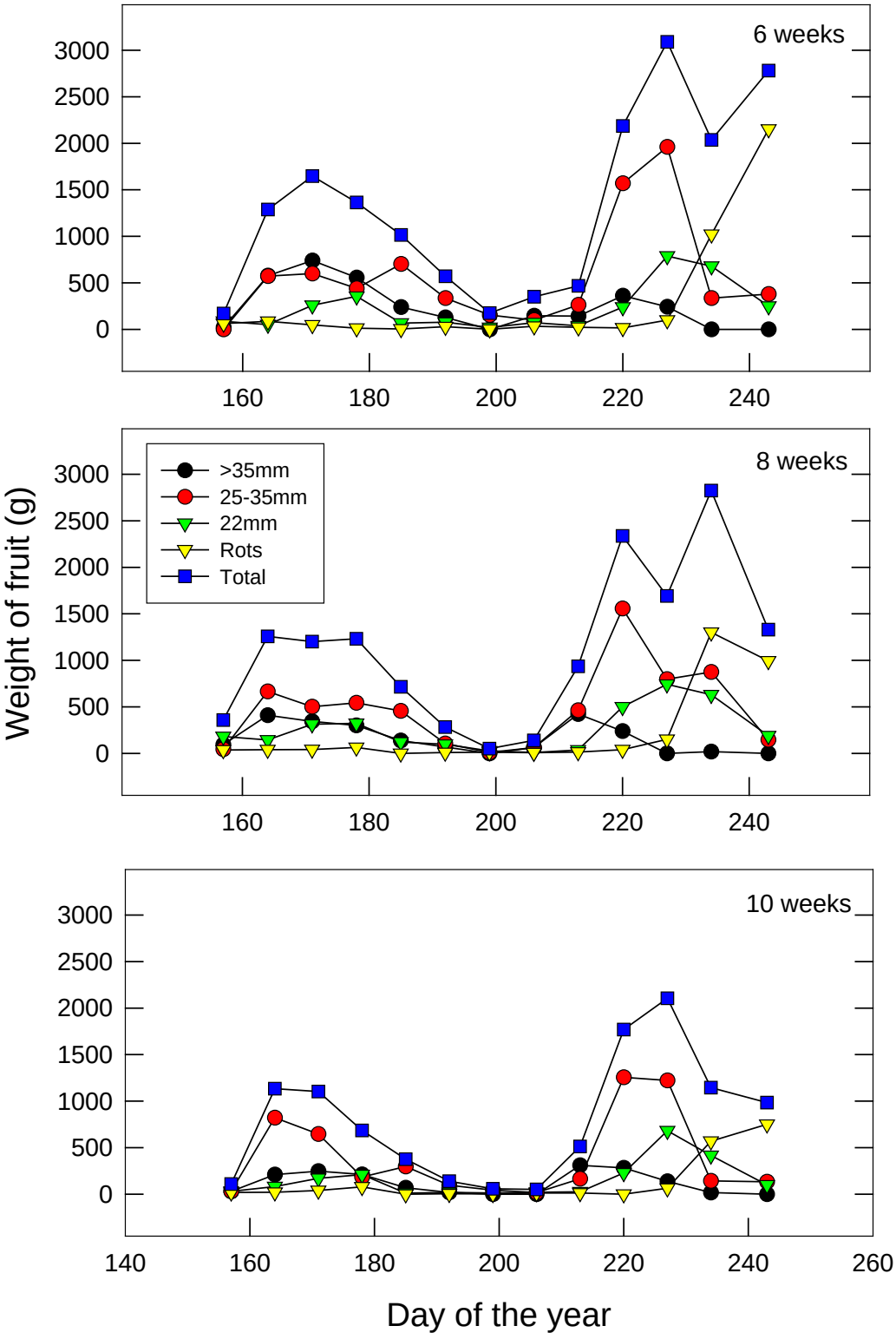


Figure 78. Effect of three chilling treatments on the weekly yields and grade-out of 'Bolero'. Top – 6 weeks chilling; middle – 8 weeks chilling; bottom – 10 weeks chilling.

Experiment 2 Determination of the Chilling Requirements of the Cultivar Everest

Materials and Methods

Plant Material

Module plants of 'Everest' were obtained from Edward Vinson Plants in early October 2000. The modules were immediately repotted into 9cm pots, using standard peat compost (Professional Potting Compost, Westland Horticulture) and placed in a glasshouse maintained at a minimum of 5^{o}C, under natural daylight conditions. Plants remaining under these conditions throughout the winter period formed treatment 1. The majority of plants were moved from the glasshouse to an unheated polythene tunnel in mid November 2000. One batch of plants then remained in this tunnel throughout the winter period, forming treatment 2.

The five chilling treatments (2-6) involved transferring batches of plants from the unheated polythene tunnel, into coldstores at –2^{o}C or +2^{o}C for either 4 or 8 weeks: for treatments 4 & 6, plants were transferred to the coldstores in early January 2001, while for treatments 3 & 5 plants were transferred during early February 2001. Plants for treatment 2 remained in the polytunnel throughout and were used as a commercial control. All plants were moved from the coldstores to the polythene tunnel in the first week of March 2001. At the beginning of April 2001, plants from all six treatments were repotted into 2 litre pots, using standard peat compost (Professional Potting Compost, Westland Horticulture) and established in an un-heated polythene tunnel ready for cropping. Detailed records of yield and quality grade-out were taken.

In addition, further plants of each treatment were established in the polytunnel (36 plants/treatment) for destructive sampling at four-week intervals during the cropping season. An initial destructive sampling was taken at the time of plant establishment in the polytunnel. After sampling, plants were divided up into component parts (leaf laminae, petioles, crowns, roots, and flowers/fruit); measurements were taken of leaf number, laminae area, petiole length, number of crowns and crown diameter. Subsequently, all plant parts were dried in an oven (80^{o}C) to determine dry matter distribution.

Experimental Design

The experiment was conducted with 10 single-plant replications of the 6 treatments, giving 60 plants in total, in a randomised block design. The six chilling treatments were as follows:

1. Glasshouse (5^{o}C)
2. Control (commercial practice) in a polythene tunnel
3. 4 weeks at +2^{o}C
4. 8 weeks at +2^{o}C
5. 4 weeks at –2^{o}C
6. 8 weeks at –2^{o}C

In addition, a further set of plants was grown for destructive sampling, as described previously. Starting in early April 2001, six plants from each treatment were taken at approximately 4-week intervals until the final sampling in mid-September.

Results

Distribution of Plant Dry Matter

Destructive analysis of dry matter distribution was carried out throughout the cropping experiment after the plants had completed their respective chilling treatments (by early March). This analysis was performed at the beginning of April and repeated at 4-weekly intervals until early September. The results are shown in Figures 79 through 81. At the start of the cropping experiment (April) plants which had received what might be considered the commercial chilling treatment (polytunnel over wintering) were the largest at around 3g dry weight per plant (Figure 79). For this treatment, about two-thirds of the plants' dry weight was due to above ground material (crowns, petioles and leaf laminas). Plants that had been given 4 weeks of chilling at –2^{o}C were slightly smaller than the polytunnel treated plants. All the other treatments produced plants with mean dry weights of around 1.5g or less. Those treatments that had exposed the plants to higher temperatures during the dormant season (glasshouse, 2^{o}C for 4 and 8 weeks) had the lowest dry weights.

At the time of the next sampling in May, above ground growth had generally begun to make a significant contribution to plant dry weight (data not shown). After 4-weeks of growth, plant size

had doubled for some treatments from 3 to 6g. The earlier negative influence of the warmer treatments had begun to disappear, with the exception of the glasshouse treatment. The plants chilled at -2^0C for 4 weeks were now the largest. By the end of May, with the exception of the glasshouse treatment (>10g), all treatments had mean plant dry weights around 15g. At the end of June the polytunnel plants weighed around 40g and were similar in weight to those that had been chilled for 4 and 8 weeks at -2^oC (Figure 80). Those held at the warmer temperatures (glasshouse treatment and the two 2^oC treatments) were much smaller, i.e. around 20g per plant. In June, the contribution of the petioles to the total plant dry weight was shown to increase for all treatments. By mid-July total plant dry weight was around 30g per plant irrespective of treatment. The plants remained around this size until the cropping trial was finished (Figure 80).

Fruit Production During the Cropping Trial

At the end of the cropping trial the total number and total weight of crop produced per plant, including all fruit classes and waste fruit, was summed (Figure 81). The different chilling treatments ranged in number of fruit from around 80 to 120 per plant, i.e. 30% variation. Fruit weight per plant varied from around 800 to 1100g; showing a similar degree of variation. The treatments that produced the largest number of fruit, and the highest weight, were the polytunnel and 4 weeks at -2^oC (Figure 81).

Fruit production rates increased with time and were close to maximal (just over 30 fruit per 4-week period) around the time of the last two samplings, i.e. late August and early September (Figure 82 – top). Crop weight was much more evenly distributed with a large amount of fruit weight appearing in July as well as August and September (Figure 82 – bottom). Fruit production has been further analysed by separating the crop into a range of size classes (Figures 83 and 84). The greater production of fruit, with respect to weight, early in the season (June and July, see Figure 83) can be attributed to the picking of larger sized fruit, particularly in the greater than 35mm diameter fruit class. The weight of waste fruit was initially very small (May through to July) but increased by late August and September (Figure 84). The waste fruit class was primarily made up of fruit less than 22mm diameter or severely misshapen.

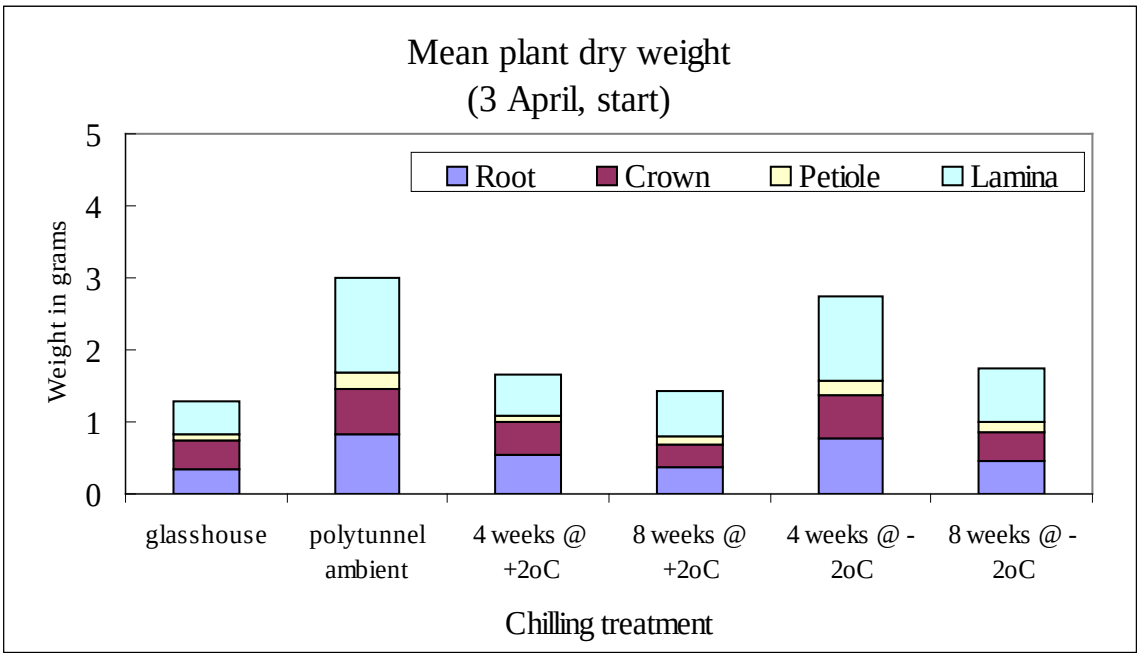
Runner Production

Runner production did not start until late May. All treatments produced runners, with the exception of the glasshouse treatment, in which plants had been held at 5°C. There was some evidence that mid-summer runner production was lower in the two treatments given 4 and 8 weeks at +2°C. Initially, the dry matter allocation to runners showed that the early runners were the smallest. However, after the end of June, runner size was not influenced by time of year. By the time of the final sampling in September each treatment had allocated around 12g of dry matter to runner production.

Discussion

As with the 'Bolero' experiment, there were initial marked differences in 'Everest' plant size after chilling. Plants that had been kept above 5°C in the glasshouse treatment were the smallest, while those which remained in the polytunnel (commercial control) throughout the winter, were the largest. Those plants that were given a 4, or 8 week exposure to +2°C also produced small plants. This suggests that plants that received no chilling were limited in size. The climate data collected showed that there were a number of low temperature events that would have contributed to the chilled status of the polytunnel plants. The winter of 2000-01 was at times colder than many of the previous winters in the 90s. It was generally true, that the polytunnel plants remained the largest throughout the cropping period relative to the other treatments, while those previously held at 4 and 8 weeks at +2°C were the smallest.

In terms of cropping, the polytunnel and the 4 weeks at -2°C treatment yielded the largest crop with respect to both number and weight of fruit per plant. There was little evidence to suggest that the fruit quality in either of these two treatments was any worse than in the other treatments. As would be expected, fruit production increased at the start of the season. However, a good volume (15 fruit or 100g per plant per 4 weeks) of marketable class 1 fruit per plant was still being produced well into September. Early fruit production irrespective of treatment was dominated by the production of large sized fruit. By late August the production of >35mm fruit had fallen considerably from that in June.



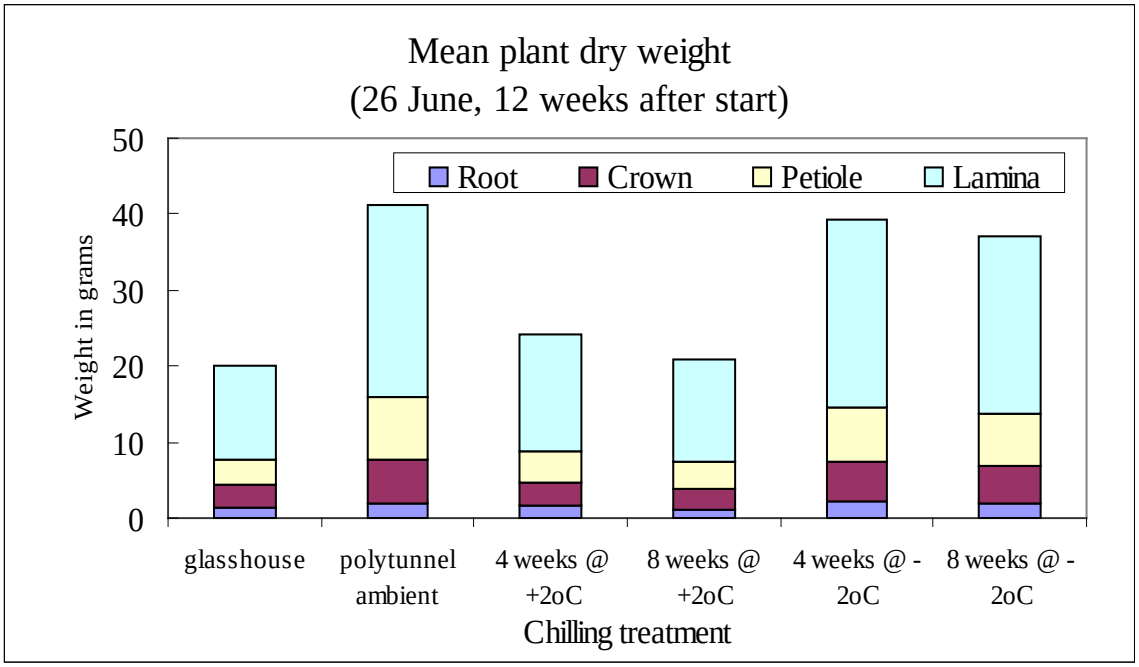


Figure 79. The distribution of dry matter Early April (week zero, top) and in late June (week 12, bottom) to roots, crowns, petioles and laminas of Everest plants subject to a range of dormant season chilling treatments. The glasshouse treatment was maintained at 5^0C minimum.

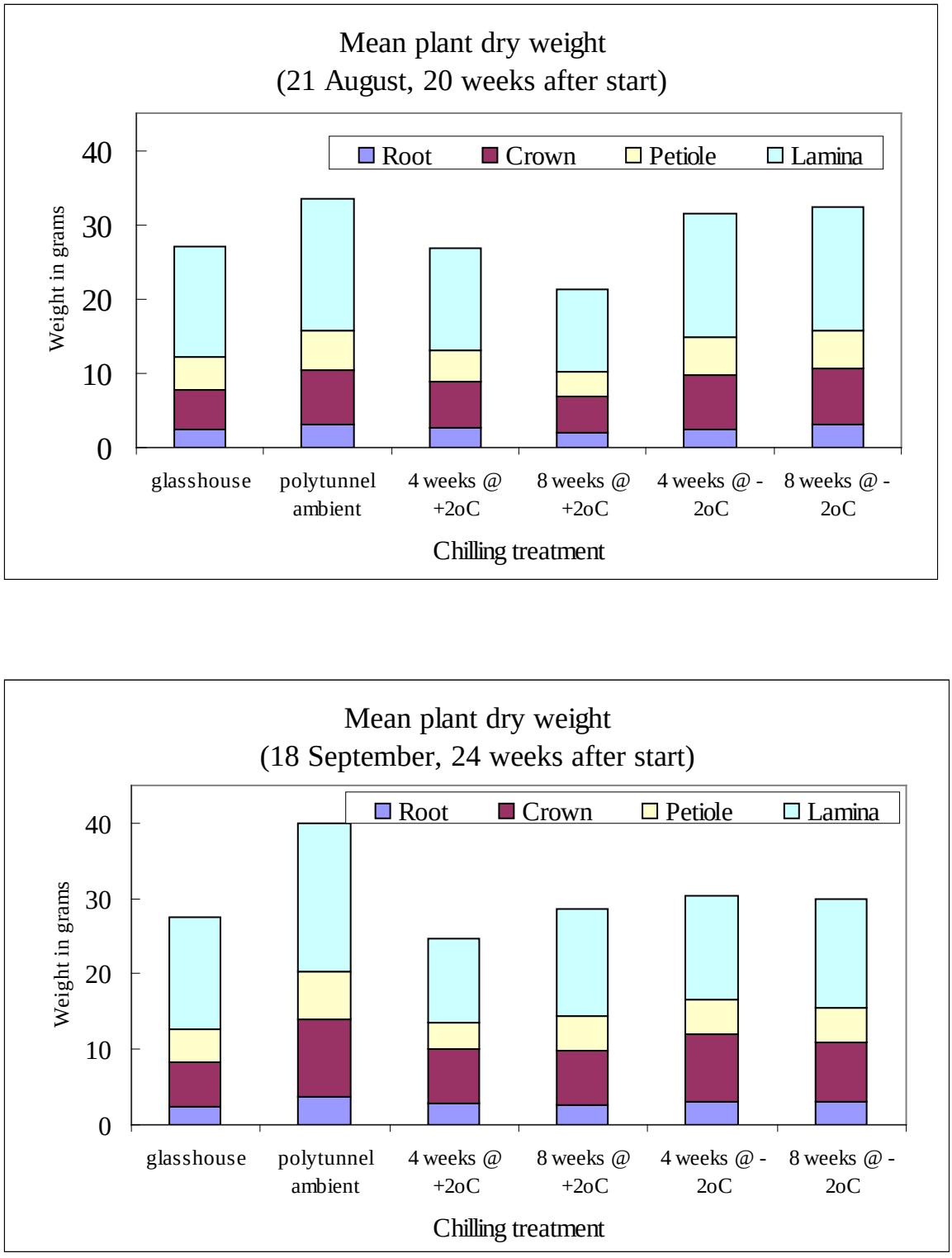
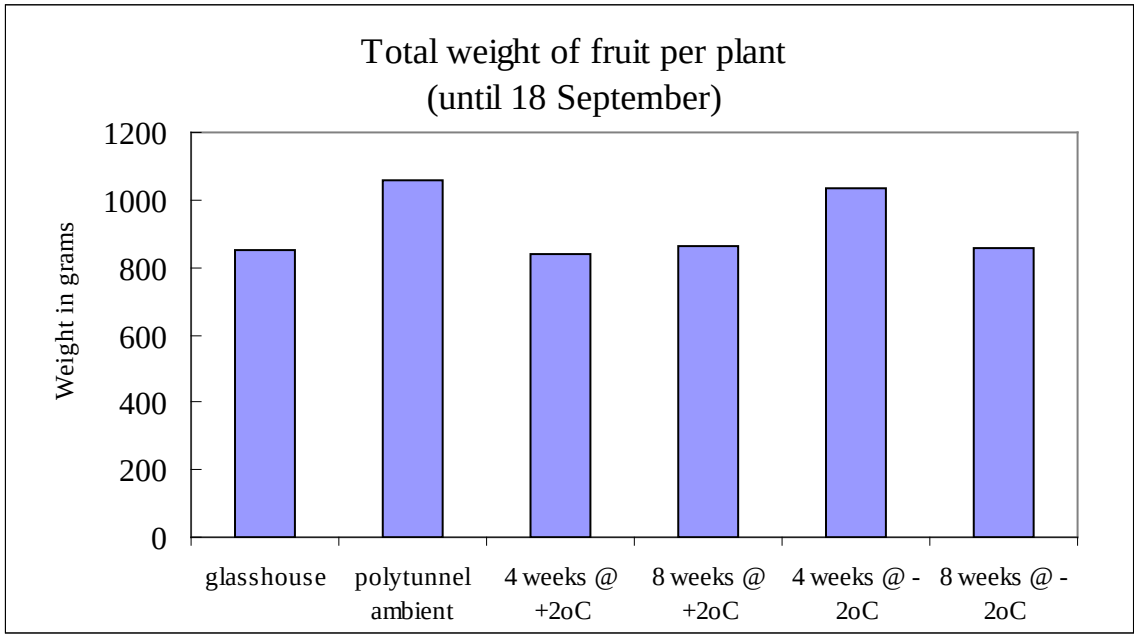


Figure 80. The distribution of dry matter in mid August (week 20) and mid September (week 24) to roots, crowns, petioles and laminas of Everest plants subject to a range of dormant season chilling treatments. The glasshouse treatment was maintained at 5^0C minimum.



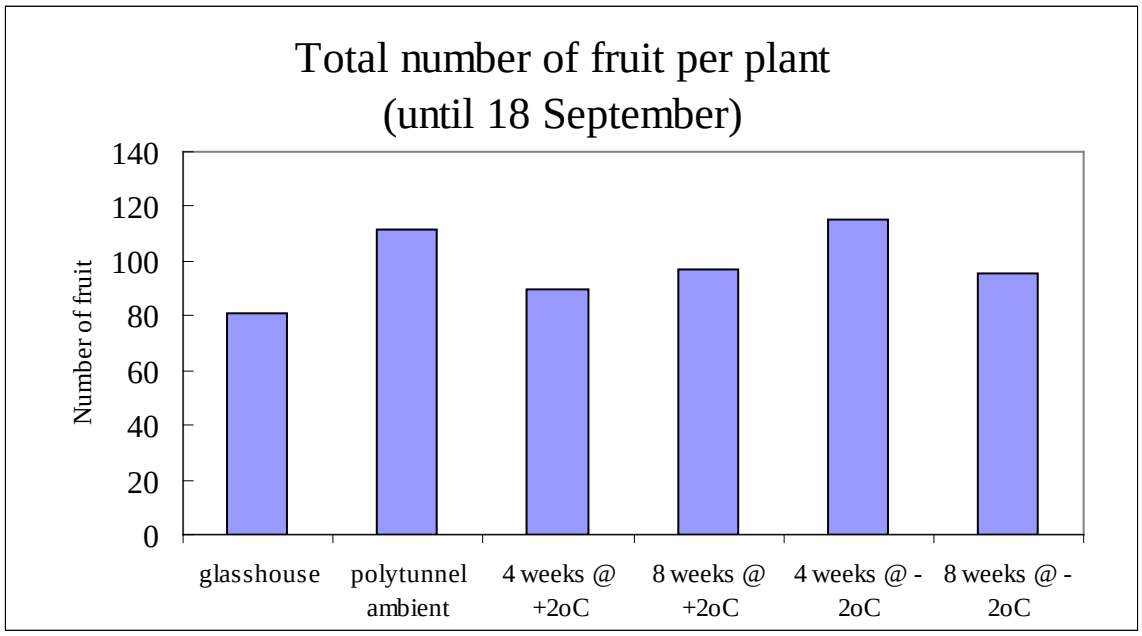
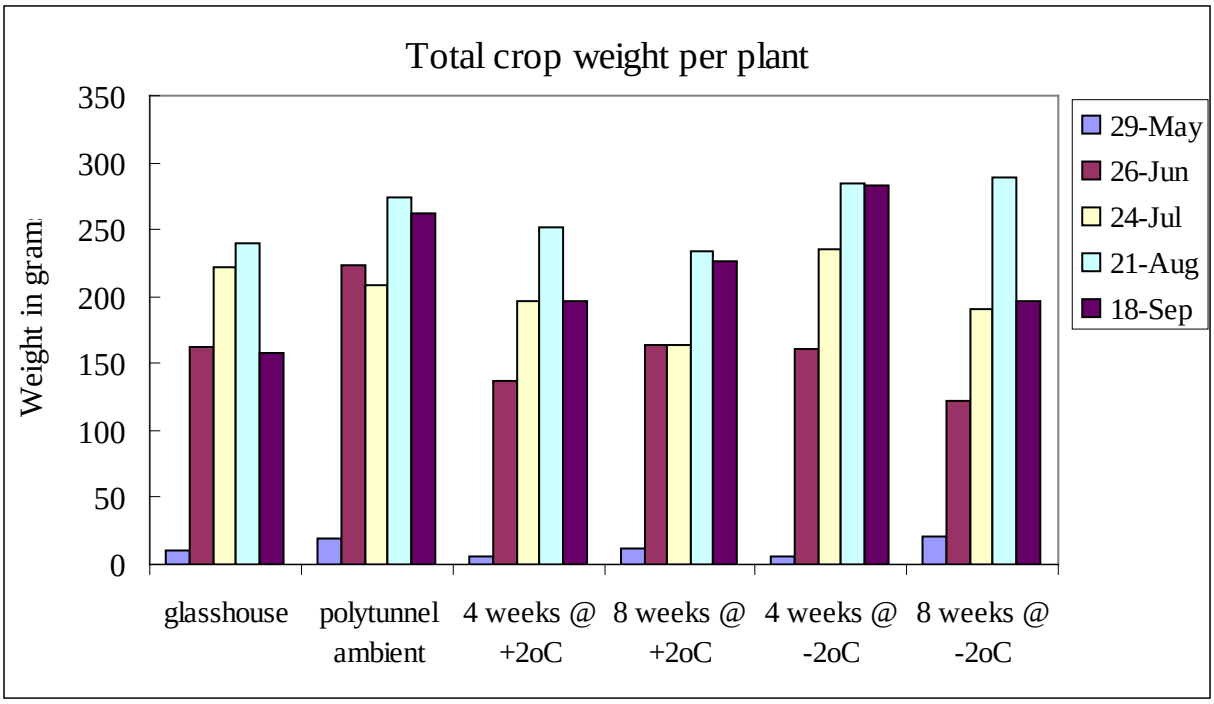


Figure 81. Total weight of fruit (g) and total number of fruit (all classes together) per plant recorded from July through to October for 'Everest' plants subject to a range of dormant season chilling treatments.



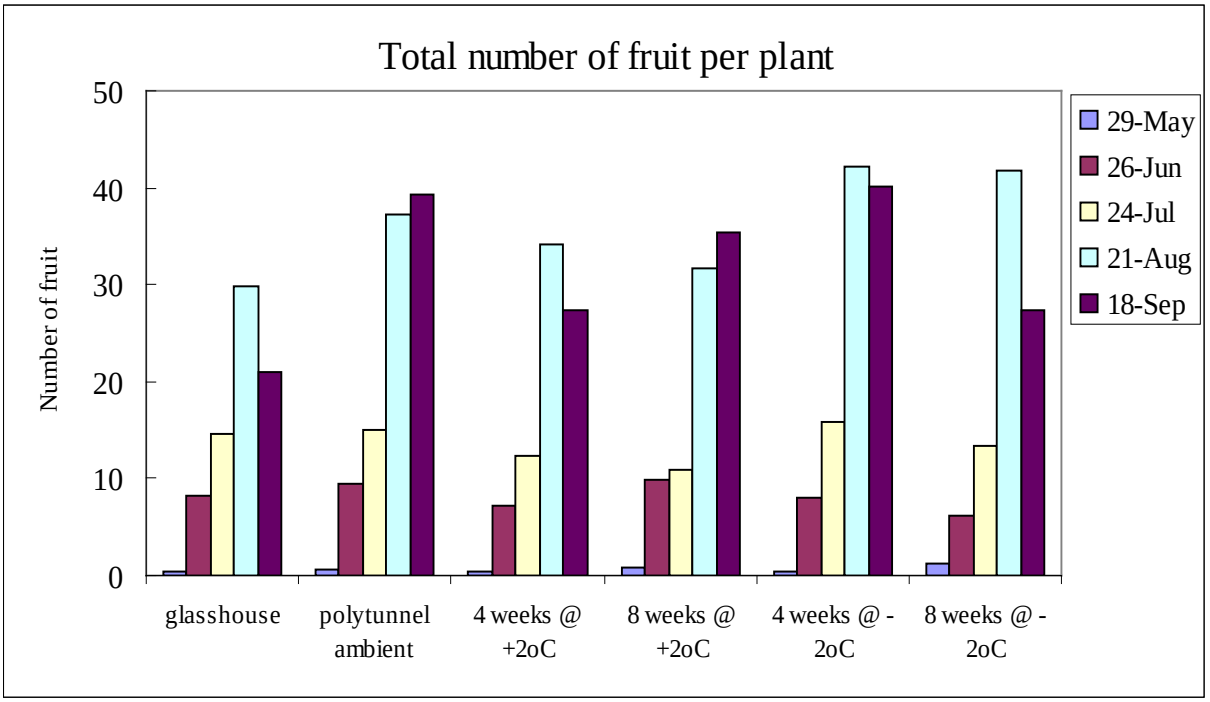
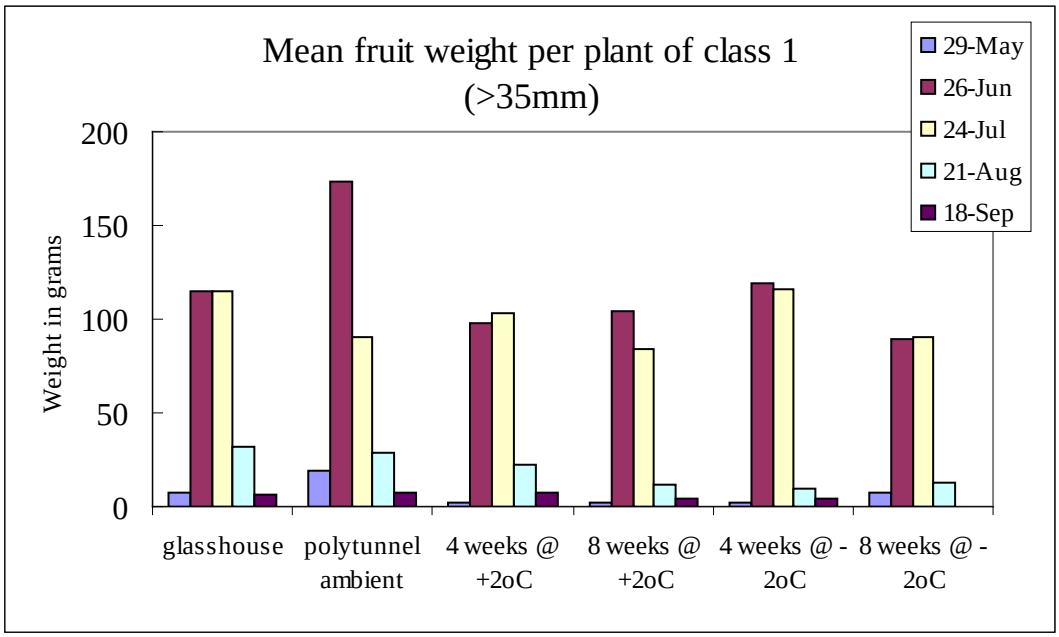


Figure 82. The mean total weight (g) and total number for fruit picked (all classes together) per plant recorded from July to October for 'Everest' plants subject to a range of dormant season chilling treatments. Data are expressed relative to the 5 picking intervals between dry matter samplings.



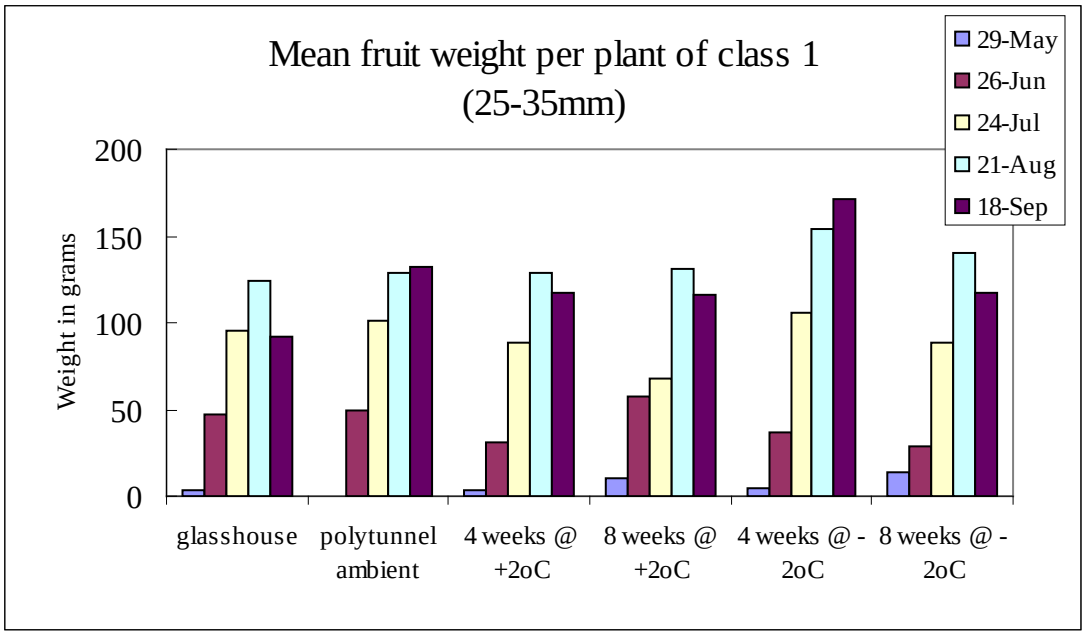
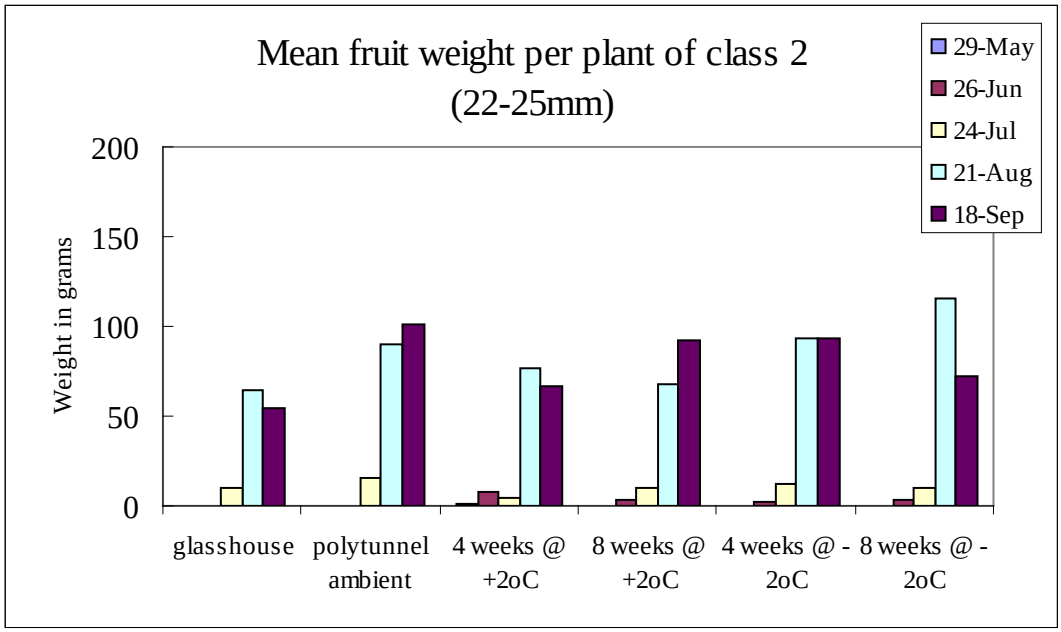


Figure 83 The mean total weight (g) per plant for fruit picked in class 1 size category (>35mm, top and 25-35mm bottom) recorded from July to October for 'Everest' plants subject to a range of dormant season chilling treatments. Data are expressed relative to the 5 picking intervals between dry matter samplings.



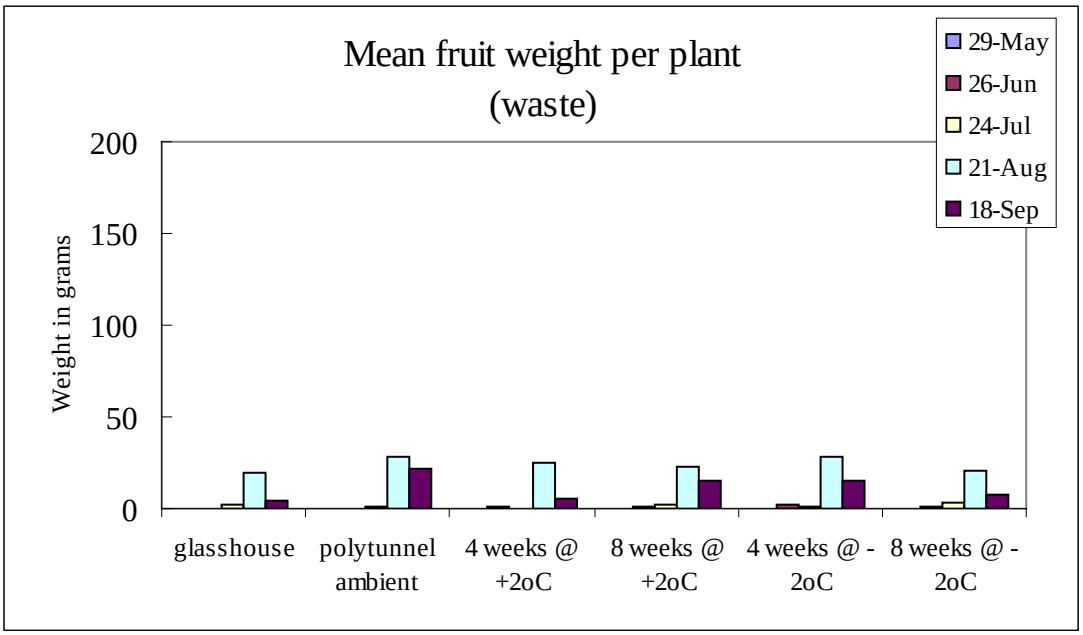


Figure 84. The mean total weight (g) per plant for fruit picked in class 2 and waste size category (22-25mm, top and waste bottom) recorded from July to October for 'Everest' plants subject to a range of dormant season chilling treatments. Data are expressed relative to the 5 picking intervals between dry matter samplings.

Experiment 3 Refining the Chilling Requirements of the Cultivar Everest

Materials and Methods

Plant Material

Module plants (540 plants) of 'Everest' were obtained from Edward Vinson Plants in early December 2001 and immediately repotted into 9cm pots, using standard peat compost (Professional Potting Compost, Westland Horticulture). The potted plants were placed in a glasshouse maintained at a minimum of 5^{o}C, under natural daylight conditions. The warmer conditions, compared to a polytunnel, are not ideal due to the extent of the shock received when plants are rapidly transferred to chilling. However, this was unavoidable due to stringent plant health regulations. One set of plants (treatment 1) remained in the glasshouse throughout the entire winter period. In mid-December 2001 another set of plants was transferred from the glasshouse to a ventilated polytunnel (treatment 2, the standard commercial practice). Chilling treatments (3-6) involved the transfer of batches of plants from the glasshouse, into coldstores at +2^{o}C for 4 weeks and –2^{o}C for 2, 6 and 10 weeks respectively. Treatment 6 plants were transferred to the –2^{o}C coldstore in early January 2002, treatment 5 plants in early February 2002 and treatment 4 plants in early March 2002. Plants for treatment 3 were transferred to +2^{o}C in mid-February. In mid-March 2002 all the plants were moved from the coldstore and glasshouse to the polytunnel, and repotted into fresh compost in 2 litre pots and arranged into their experimental randomised positions.

Experimental Design

The experimental design for the seasonal analysis of dry matter partitioning was as with the previous experiment (2), with 6 single-plant replications sampled at monthly intervals over the 6 month cropping season. This was achieved using randomised block design for all 6 treatments, giving a total of 216 plants (6 treatments x 6 replicates x 6 samplings). The experimental treatments were as follows:

1. Glasshouse (>5^{o}C)
2. Control (commercial) in a polythene tunnel throughout the entire winter
3. 4 weeks at +2^{o}C
4. 2 weeks at -2^{o}C
5. 6 weeks at –2^{o}C
6. 10 weeks at –2^{o}C

An initial destructive sampling was undertaken when the plants were established in the polytunnel. After sampling, plants were divided up into component parts (leaf laminae, petioles, crowns, roots, and flowers/fruit); measurements were taken of leaf number, laminae area, petiole length, number of crowns and crown diameter. Subsequently, all plant parts were dried in an oven for measurements of dry weight.

Results

Distribution of Plant Dry Matter

Destructive analysis of dry matter distribution was carried out throughout the cropping experiment, at 4-week intervals, from early April through to mid-September. The results are shown in Figures 85 through to 90. At the start of the experiment the plants which had been chilled at –2^{0}C for the shortest amount of time, i.e. 2 weeks, where the largest (Figure 85). The next largest were those which had received no chilling and had been maintained in the glasshouse

throughout the winter (>5^{0}C, treatment 1). There was generally a trend for total dry matter to decline with increased amount of chilling. Treatment differences were most obviously apparent in the amount of lamina and petiole present. The amount of dry matter distributed to root was the next most variable plant component, again declining with chilling.

By the time of the next sampling, 4 weeks after planting, there was a distinct reduction in total dry matter for the plants in treatments that had received the largest amount of chilling (Figure 86). Treatments chilled at –2^{0}C for 6 and 10 weeks had less than half the dry matter of the glasshouse and polytunnel treatments. Much of this difference was again due to both root and lamina dry matter being much lower in the longer chilled plants. At this stage of the experiment the polytunnel treatment plants were the largest.

Analysis of dry matter distribution carried out some 8 weeks after planting showed similar treatment responses to the April sampling. Again, it was the polytunnel plants that were the largest, followed by the glasshouse treatment and the 4 and 2 week chilling treatments at +2^{0}C and –2^{0}C respectively (Figure 87). For the larger plants, the small treatment differences were due mainly to differences in lamina weight, while for the smaller plants it was the amount of root that was most influenced by treatment.

Twelve weeks after planting, the treatment differences became even less apparent, with the exception of the glasshouse treatment, all the least chilled treatments had larger plants (data not shown). There was little treatment difference in the amount of dry matter distributed to the root and crowns. With the exception of plants receiving the longest chill treatment, the major differences were due to the amount of lamina.

Dry matter distribution determined in early July, some 16 weeks after planting, was very similar to that recorded in early June. For the July sampling, plants were larger, but the treatment differences in dry matter distribution were very similar (Figure 88). As with all of the previous samples the amount of dry matter was always lowest for the plants, which had been chilled at –2^{0}C for 10 weeks. By early August (20 weeks after planting) there was little, if any, further gain in plant dry matter compared to that recorded in July. The difference between treatments was

again similar to earlier samples, with the exception of the -2^0C for 10 weeks treatment, which clearly showed the least accumulation of dry matter (Figure 89). The final destructive sampling was carried out in early September, 24 weeks after planting, again revealed no significant increase in plant dry matter for any treatment compared to the previous sampling (Figure 90).

Fruit Production During the Cropping Trial

The total number and total weight of fruit produced up until early November is shown in Figures 91 and 92. Fruit production was very similar for treatments 1 to 4, but was lower for the higher chilled plants in treatments 5 and 6, i.e. at -2^0C for 6 and 10 weeks. These differences were less marked when considering total fruit number per season (Figure 92) compared to total fruit weight per season (Figure 91). Total weight of crop produced was greatest in the months of August and September, followed by that produced in October. The weight of fruit during these months did vary with treatment. Around 500 to 600g per plant was produced on plants in treatments 1 to 4. Chill treatments 5 and 6 produced much more fruit (over 700g) in September and only about 350g per plant in August. The largest number of fruit produced during the season occurred in September, with an average of over 80 fruit per plant. This suggests that fruit size was declining, particularly with treatments 1 to 4 in September.

The total crop weight per plant and total number of fruit per plant are shown throughout the season (Figures 93 and 94). The sample intervals used in this analysis correspond to those intervals over which plants were sampled for dry matter distribution. It can be seen that for all treatments the highest numbers of fruit were obtained during August (Figure 94). A similar pattern was generally true for fruit weight, but the treatments receiving lower levels of chill (treatments 1 to 4) had similar production weights in July as well as August.

Further analysis of crop quality, into different classes by fruit size, showed that early fruit production was dominated by class one fruit, in particular the >35mm class which peaked production in August (Figures 95 and 98). However, the 25 to 35mm class 1 of fruit was much more evenly distributed over the growing season (Figure 96). Treatment differences were again mainly confined to those plants that had been chilled at either -2^0C for 6 or 10 weeks. Class 2 fruit (22-25mm) showed a peak production weight and number in September (Figure 97).

Between 30 and 45 fruit per plant were produced in September, with a fresh weight of 200 to 230g per plant. There was a much greater similarity between treatments for class two fruit than for class 1. The amount of waste fruit produced was small initially and increased with time generally peaking by September for all treatments (Figure 98).

Chilling and Fruit Production Environments

Detailed climatic records were taken throughout the experiment, including monitoring of the cold stores in which plants were chilled. Records taken in the polytunnel used for treatment 2, i.e. 'polytunnel control', over the winter period are presented in Table 38.

It can be seen that a large proportion of chilling occurred in the months of December 2001 and January 2002, while in February and March there were similar hours below 2^{o}C compared to November, but very little below zero (Table 33). In general the pattern of temperature change was similar to the previous season 2001, with the exception of warmer temperatures in the early part of the year, i.e. April 2002, and lower maximum temperatures during the height of the summer period.

Table 38. Analysis of the polytunnel air temperature recorded over the winter of 2001 to 2002. This is a record of the chilling environment for treatment 2.

	Mean air temperature	Max air temperature	Min air temperature	Hours below 2^oC	Hours below 0^oC	Hours below -2^oc
November	9.24	22.3	-0.1	28	1	0
December	4.29	18.4	-3.5	272	140	21
January	6.34	22.8	-7.4	117	91	68
February	9.35	25.7	-0.1	38	1	0
March	11.36	32.2	-0.1	32	3	0
Total No. chilling h.				**487**	**236**	**89***

*Note: This amount of total chill hours was considerably less than that for the -2^0C treatments of 2, 6 and 10 weeks duration, which have total chill hours below -2^0C of 336, 1008 and 1680 hours respectively.

Runner Production

The number and mass of runners produced by the chill treatments were determined when the destructive sampling was carried out. Runner production was only evident in June and July. The glasshouse treatment plants produced the lowest number of runners of all the treatments. It would appear from the plants chilled at -2^0C that the increase in the duration of chilling period induced almost a ten-fold increase in runner production. The polytunnel treatment also produced a similar number and weight of runners with respect to the -2^0C 10 week chill plants.

Discussion

As with both experiments 1 and 2 there were marked differences in plant size associated with chilling treatment. Plants that had been kept above 5^oC in the glasshouse treatment were largest, with the exception of those chilled -2^0C for 2 weeks. Those that had received the greatest

amount of chilling -2^0C for 10 weeks were the smallest at about half the size of those from the -2^0C for 2 weeks. In part, the smallness of the plants associated with the -2^0C chill treatments (Treatments 4, 5 and 6), particularly those for 6 and 10 weeks, is likely to be in response not only to chilling. These plants were chilled in the dark and would therefore have been deprived of any potential photosynthetic capacity during that time. Compared to the polytunnel and glasshouse plants, the chill treatment plants would have likely had little accumulated reserve carbohydrate.

In experiment 2, the glasshouse treatment had yielded the smallest plants, but it was suspected that this might have been due to problems associated with the AFP of the initial batch of potting compost. This was not the case in experiment 3 where the potting compost used had a much higher AFP value. In general, as the duration of the chilling period at -2^0C increased, the size of plant at planting declined. This effect may have been made worse by the plants having to remain in a containment glasshouse at reasonably high ambient winter temperatures, due to potential blackspot problems. When each treatment batch of plants was moved to the coldstore for chilling there would have been considerably more stress associated with the rapid change in temperature. However, by adopting this approach it meant that the treatments, which were chilled in cold storage (Treatments 3, 4, 5, and 6) all received quantifiable amounts of chilling provided during a single exposure.

The differences in plant size associated with treatment were still apparent at the final destructive sampling, but the margins of these differences were much smaller than they had been at the start of the experiment. The impact of these treatment differences on plant size was apparent in the crop. The two treatments that yielded the lowest number of fruit (around 200 per plant) and the least weight (around 1.5 kg per plant) were the chilling at -2^0C for, either 6, or 10 weeks. Treatments 1 to 4 all produced a similar number (around 250 per plant) and weight (2.0 kg per plant) of fruit over the season. Also, there were no major seasonal differences in the pattern or details of the fruit quality analysis (allocation of fruit to the various size classes), particularly associated with treatments 1 to 4.

It can, therefore, be concluded that despite the chilling treatments influencing plant size, at least initially, the effect was lost with treatments receiving less chilling (e.g. 1 to 4) and the plant size

difference had no impact on cropping performance. In terms of the most economic practice, both experiments 2 and 3 show that leaving plants to over winter in a polytunnel is the best current practice. It is, therefore, concluded from the results, with the everbearers evaluated so far, that the current industry practice of polytunnel overwinter is sufficient to satisfy chilling requirements. The likelihood of warm winters, particularly under partial protection, is a subject that will warrant further research, particularly, as the impacts of climate change become more evident and frequent. It should, however, be noted that initial growth of 'Everest' directly out of tissue culture produced very satisfactory crops in the absence of chilling and subsequently a commercial company in Canada grows this variety using this approach (personal communication from Peter Vinson).

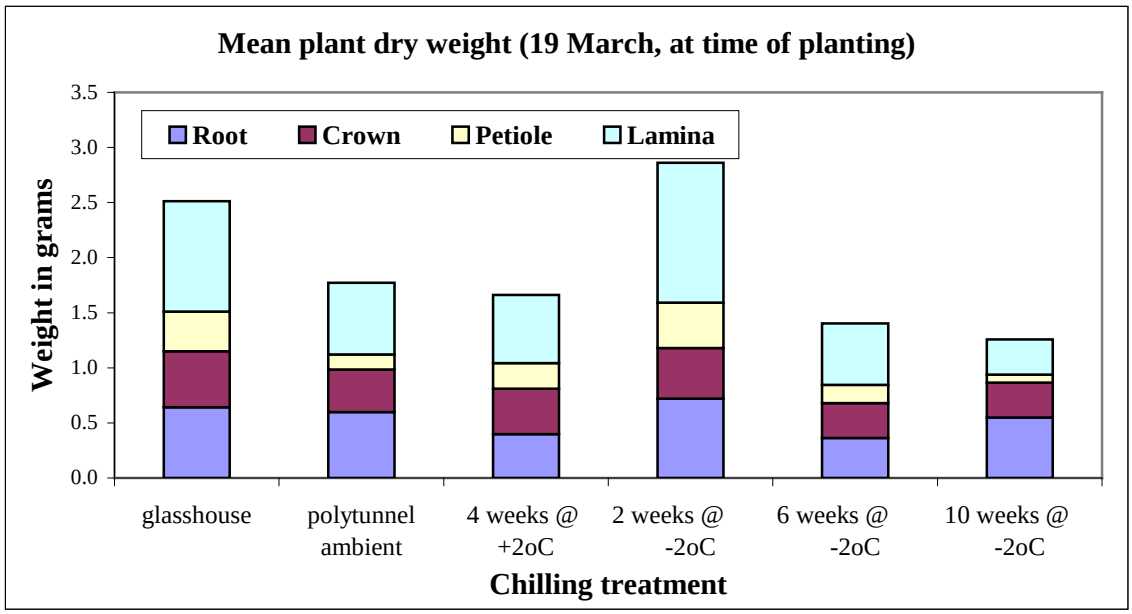


Figure 85. The distribution of dry matter to the root, crown, petiole and lamina of everbearer 'Everest' plants previously chilled under various regimes for different lengths of time and sampled on March 19 at the start of the cropping experiment.

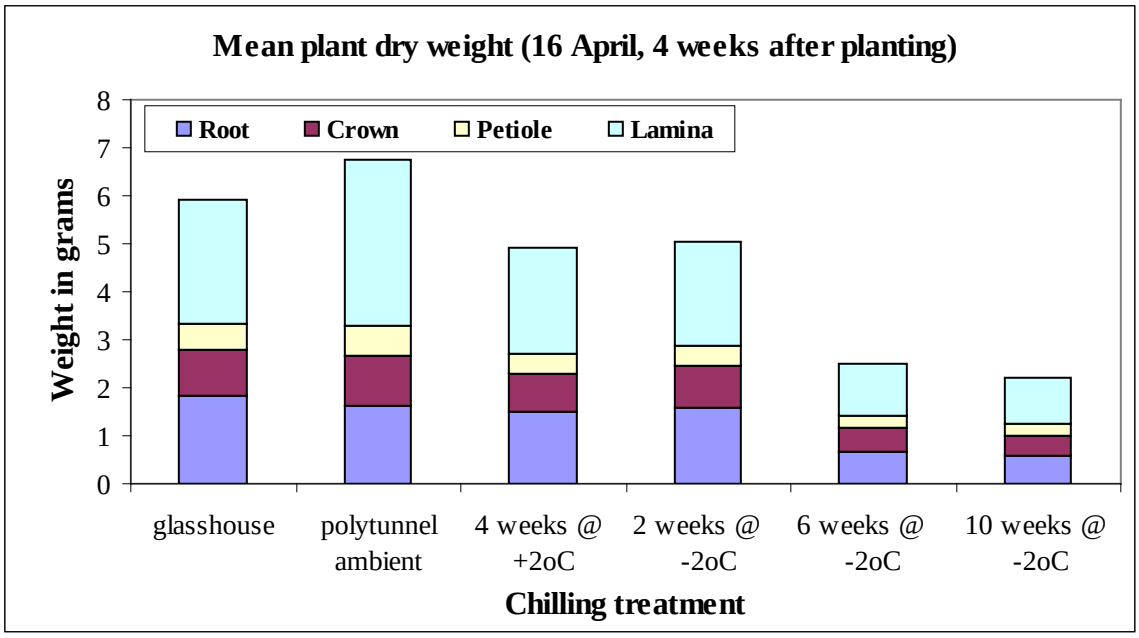


Figure 86. The distribution of dry matter to the root, crown, petiole and lamina of everbearer 'Everest' plants previously chilled under various regimes for different lengths of time and sampled on April 16, 4 weeks after planting the cropping experiment.

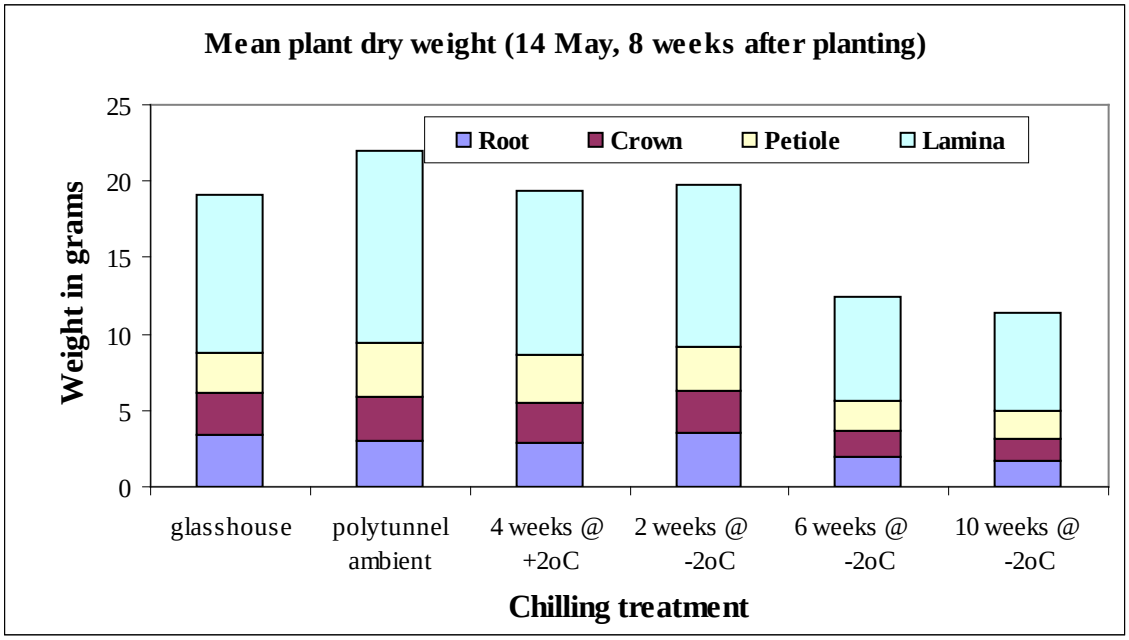


Figure 87. The distribution of dry matter to the root, crown, petiole and lamina of everbearer 'Everest' plants previously chilled under various regimes for different lengths of time and sampled on May 14, 8 weeks after planting the cropping experiment.

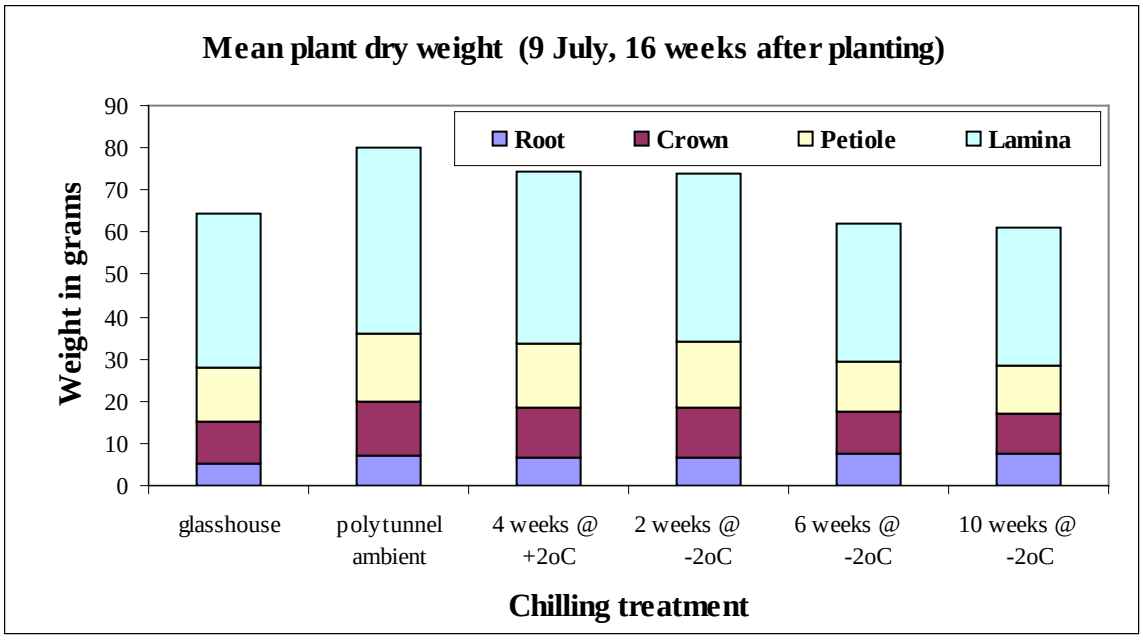


Figure 88. The distribution of dry matter to the root, crown, petiole and lamina of everbearer 'Everest' plants previously chilled under various regimes for different lengths of time and sampled on July 9, 16 weeks after planting the cropping experiment.

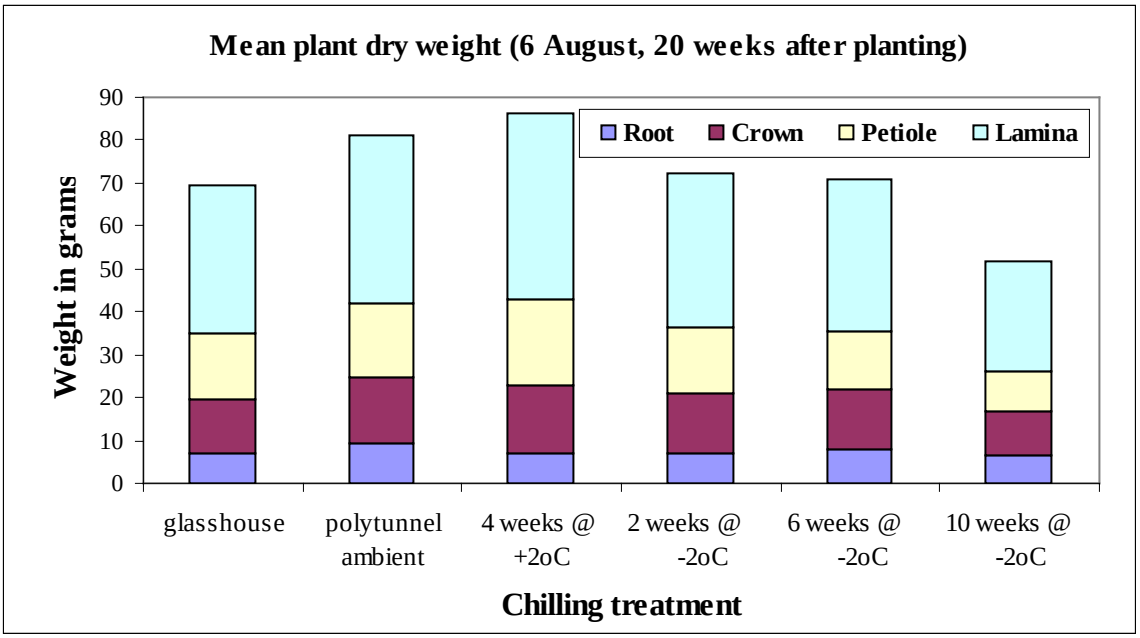


Figure 89. The distribution of dry matter to the root, crown, petiole and lamina of everbearer 'Everest' plants previously chilled under various regimes for different lengths of time and sampled on August 6, 20 weeks after planting the cropping experiment.

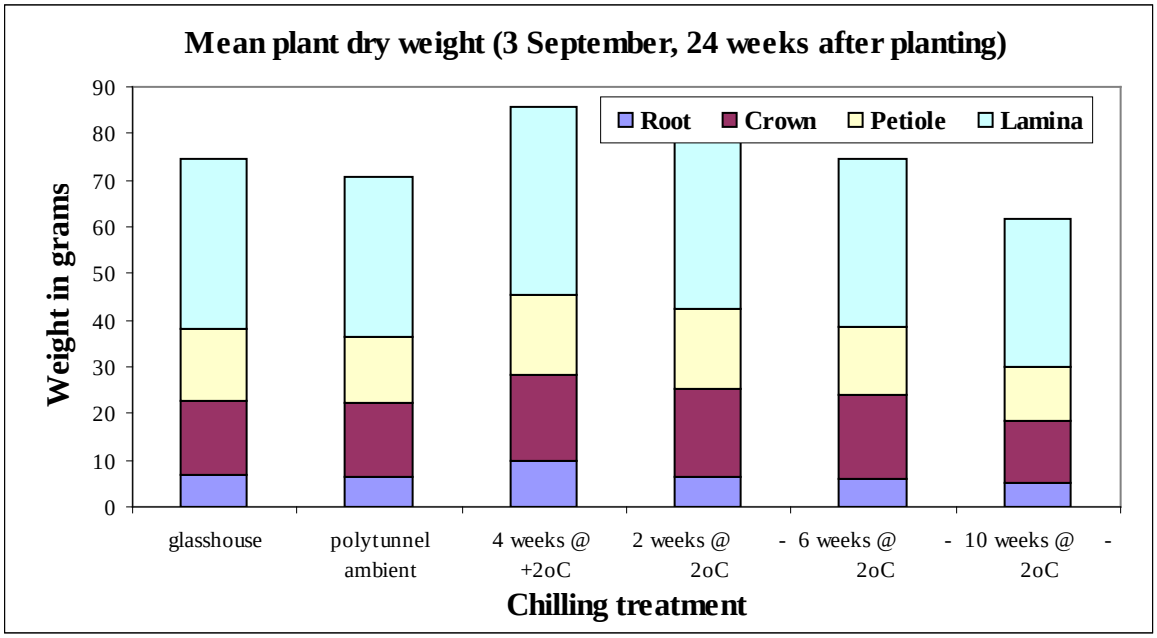


Figure 90. The distribution of dry matter to the root, crown, petiole and lamina of everbearer Everest plants previously chilled under various regimes for different lengths of time and sampled on September 3, 24 weeks after planting the cropping experiment.

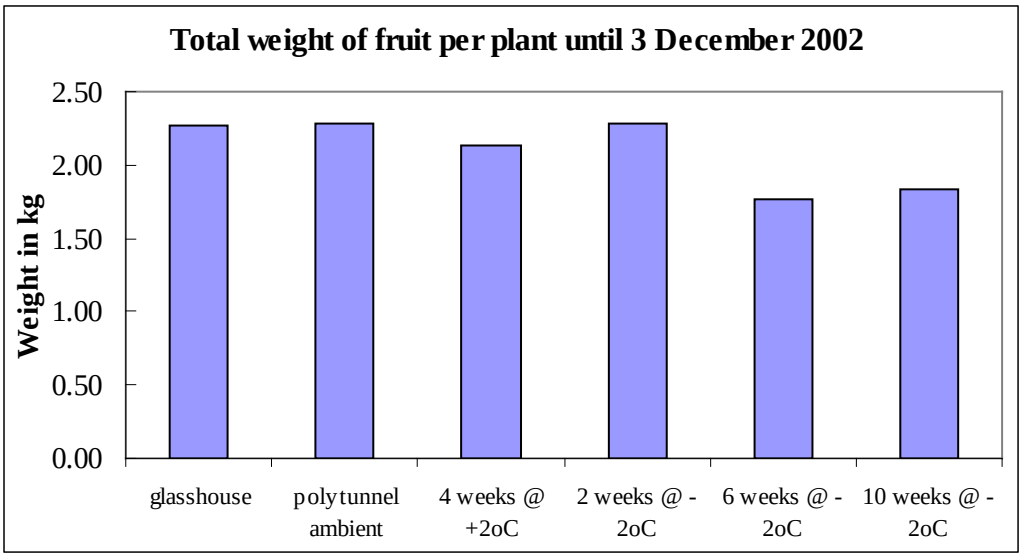


Figure 91. Total weight of fruit (all classes together) per plant recorded from May through to December for 'Everest' plants subject to a range of dormant season chilling treatments

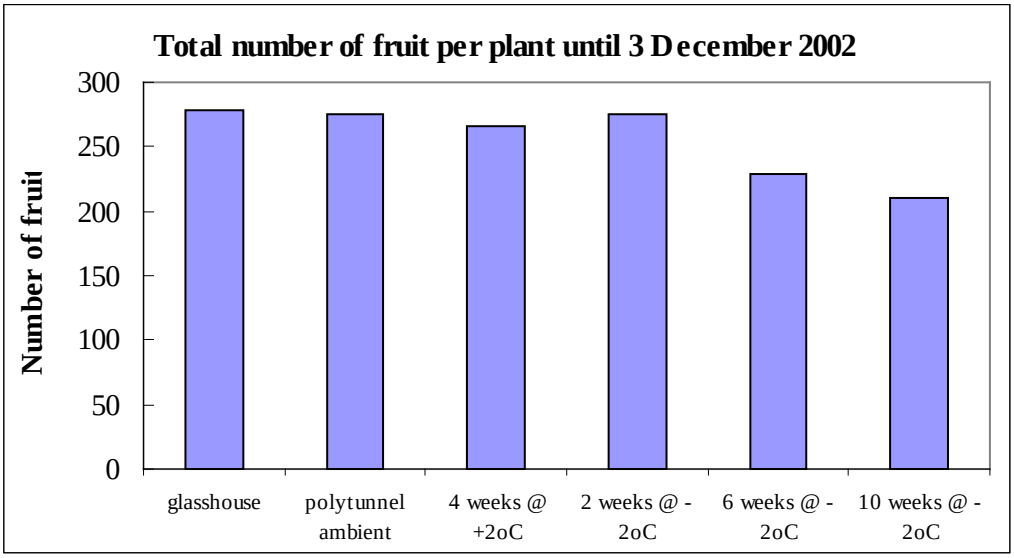


Figure 92. Total number of fruit (all classes together) per plant recorded from May through to December for 'Everest' plants subject to a range of dormant season chilling treatments

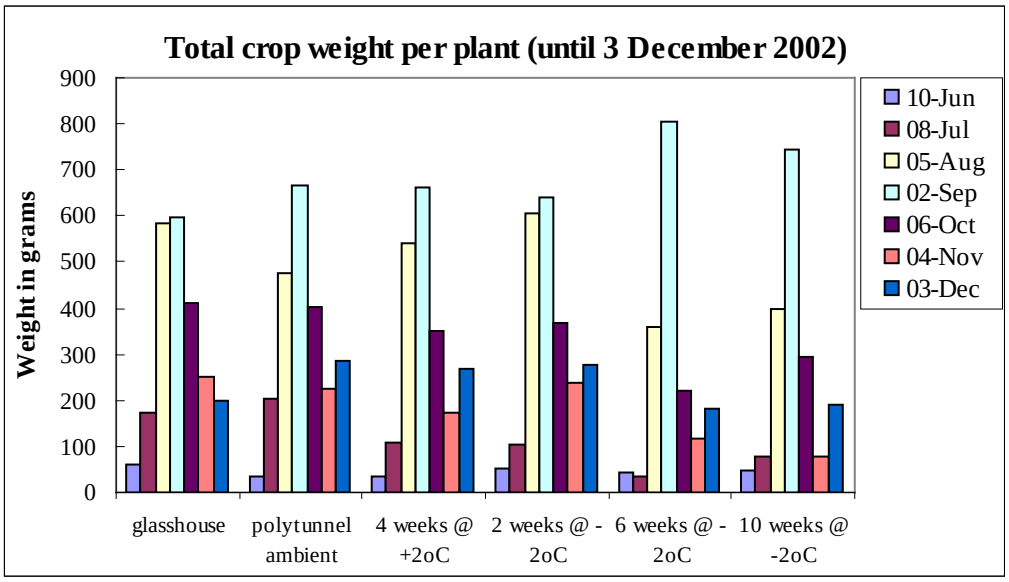


Figure 93. The mean total weight (g) for fruit picked (all classes together) per plant recorded from June to December for 'Everest' plants subject to a range of dormant season chilling treatments. Data are expressed relative to the 7 picking intervals between dry matter samplings

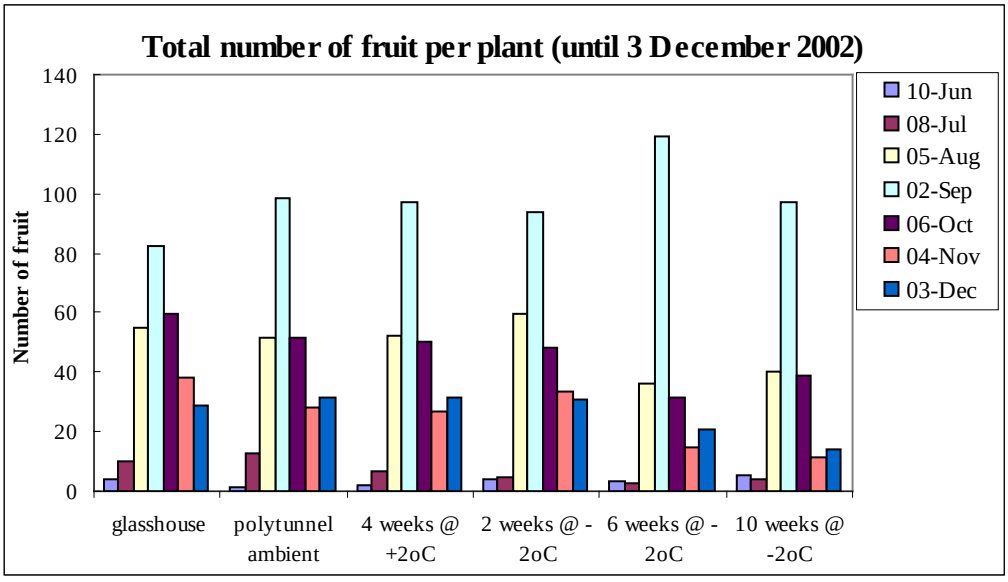


Figure 94. The mean number for fruit picked (all classes together) per plant recorded from June to December for 'Everest' plants subject to a range of dormant season chilling treatments. Data are expressed relative to the 7 picking intervals between dry matter samplings.

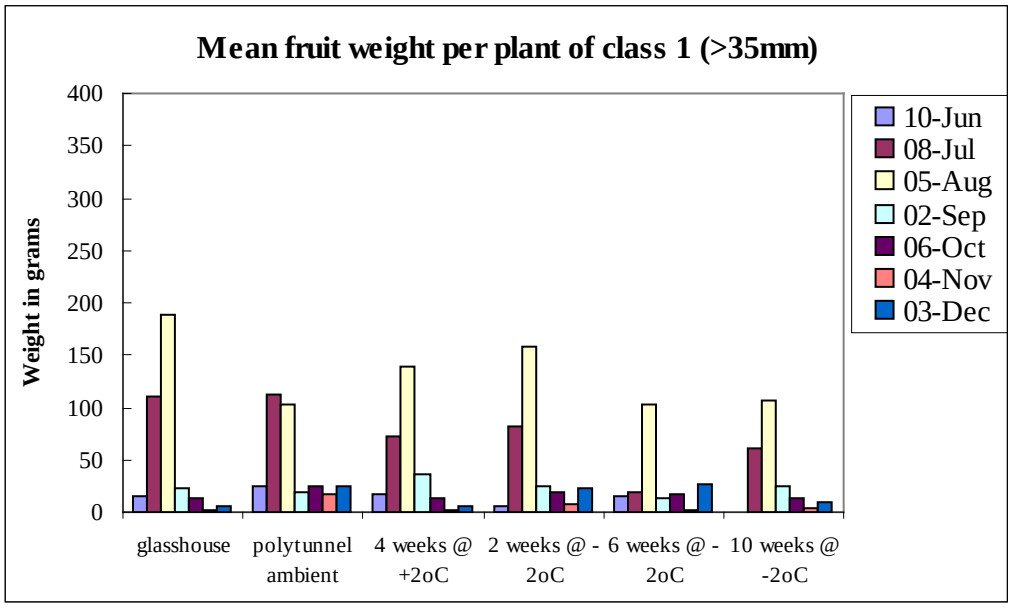


Figure 95. The mean weight of class 1 (>35mm) fruit picked per plant recorded from June to December for 'Everest' plants subject to a range of dormant season chilling treatments. Data are expressed relative to the 7 picking intervals between dry matter samplings.

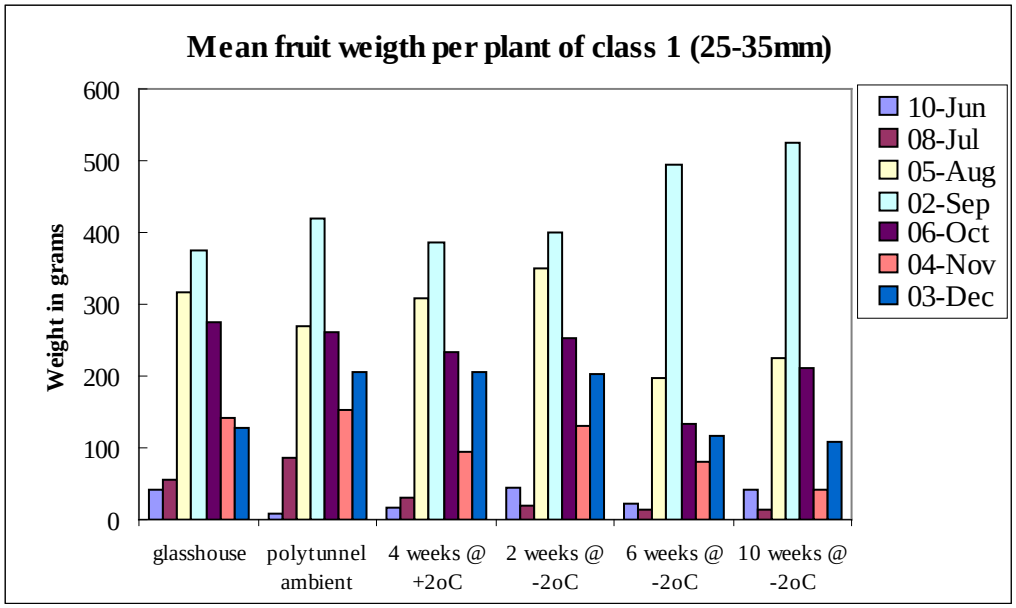


Figure 96. The mean weight of class 1 (25-35mm) fruit picked per plant recorded from June to December for 'Everest' plants subject to a range of dormant season chilling treatments. Data are expressed relative to the 7 picking intervals between dry matter samplings.

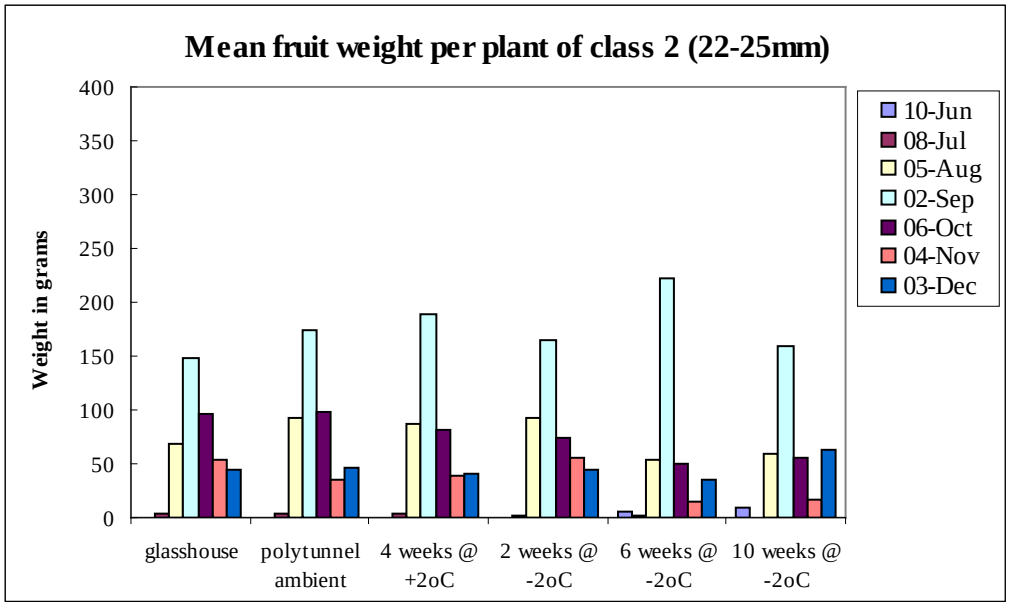


Figure 97. The mean weight of class 2 (22-25mm) fruit picked per plant recorded from June to December for 'Everest' plants subject to a range of dormant season chilling treatments. Data are expressed relative to the 7 picking intervals between dry matter samplings.

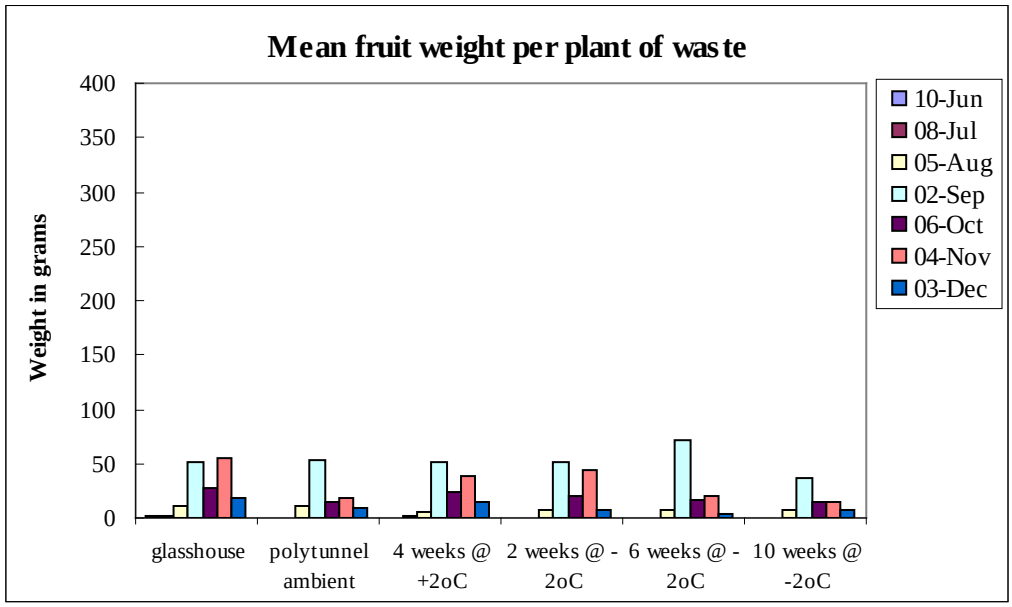


Figure 98. The mean weight of waste for fruit picked per plant recorded from June to December for 'Everest' plants subject to a range of dormant season chilling treatments. Data are expressed relative to the 7 picking intervals between dry matter samplings.

Assess Effects of Runner Variability on Plant Performance

Introduction

The developmental morphology of stolons or runners produced by strawberries has been described previously (White, 1927; Guttridge, 1955) these being specialised branches which develop from axillary buds in the crown of the plant. Initially the stolon grows by elongation of the first two internodes, with a runner plantlet being formed at the second node. A "continuation" stolon is usually formed, developing from an axillary bud in the first plantlet, and this continues to develop, with the formation of another plantlet at the second node. Further development of continuation stolons and plantlets can occur in the same manner, forming a runner series or "train" which can contain over twenty plantlets (Robertson and Wood, 1954).

The propagation of everbearing cultivars often involves the use of systems whereby "mother" plants (MPs) are grown in containers with a peat-based substrate under glass, the containers being elevated off the ground. The stolons produced are left to cascade down vertically, with several plantlets on each stolon, and are harvested when the tip of the stolon reaches the ground. Plantlets from each stolon are then separated and used for propagation by rooting in small modules, again using peat-based media. The plantlets from each stolon are all of different ages and sizes, depending on their position relative to the MP, the primary or first order, plantlet nearest the MP being the oldest. However, it is not clear whether this initial plantlet-to-plantlet variability has any carry-over effects on subsequent plant development and in particular, any consequences for the potential cropping performance of the plants. Results of a preliminary study with the Everbearer cultivar Selva, in which the reproductive development of plants originating from the second and third order positions on the stolon was compared, indicated higher early season yields from the former (Hamann and Poling, 1997).

Part of the work in task 4 has been designed to evaluate the potential influence of the original position on the stolon, on the subsequent plant development and cropping potential of the Everbearer cultivar Everest. In ecological terms the strawberry is a clonal plant, with the

plantlets formed on stolons being known as “ramets” (Alpert, 1986). Hereafter the term ramet will be used in the report of the experimental work.

Materials and Methods

Plant Material and Experimental Design

Plant material of the cultivar Everest was collected from the commercial propagator, Edward Vinson Plants (Sandbanks, Graveney, Faversham, Kent (experiment 1) and Bonnington, near Ashford (experiment 2)). Two pot experiments were carried out to evaluate ramet performance, the first involved looking at establishment and vegetative growth, while the second, a longer experiment, also looked at polytunnel cropping of established ramets. In the first experiment, ramets were collected in October, while for the second they were collected in late August. The design of both experiments was similar, with the exception that, information collected in the second experiment enabled the performance of all the four ramets from a stolon to be related back to their sibling ramets on the same stolon.

Stolons with 4 ramets (commonly known as runner “tips”) were selected and removed intact from mother plants; a total of around 250 stolons were collected and placed into black plastic bags for transfer to East Malling. Immediately on arrival, the stolons were removed from the bags and placed onto a mist bench, in order to maintain them in a moist condition until separation and planting was completed. The ramets were labelled hierarchically, with the closest to the point of origin from the mother plant being designated the ‘primary’ (or 1st order), and with those at the successively lower order positions on the stolon being designated the secondary, tertiary and quaternary respectively. Ramets were separated from the stolon, leaving approximately a 2cm length of the stolon on the proximal side. In line with commercial practice, any damaged, diseased or necrotic leaves, together with any flowers or fruit, were removed. Any remaining mature leaves were also removed, so as to leave only one mature and any remaining younger leaves.

After being dipped into a solution of the fungicide Benlate, the ramets were planted or ‘stuck’ into 7 cm pots, containing a peat/loam (9:1; v:v) compost with controlled release fertiliser

(Osmocote Plus; 15+8+11+2 + trace elements; 12-14 month) added at 4 kg m^{-3}. Thirty modules were then placed into supporting trays, with each tray containing ramets of the same order. The trays were then placed onto a mist propagation bench, situated in a glasshouse, and were regularly misted at intervals to maintain the leaves in a constantly moist condition. The temperature in the glasshouse was maintained at a minimum of 10^{o}C, under natural daylight. Each tray of ramets formed a replicate, the experiment consisting of 6 replications arranged in a randomised block design. This entire operation was completed on the same day the stolons were collected.

In addition, a further 12 ramets from each position were prepared as described above, and then taken to the laboratory. Each ramet was then divided up into component parts as follows: roots, crowns, petioles and leaf blades (laminae). These plant parts were then placed into individual glass tubes and the tissues killed by immersion in liquid nitrogen. The samples were then transferred to a freeze drier and dried until a constant weight was reached. The dry weights of the samples were then recorded and the tissues kept in a freezer at -20^{o}C until required for further mineral and carbohydrate analyses.

In early December, the plant material was removed from the misting bench and transferred to another glasshouse, maintained at a minimum temperature of 10^{o}C, with natural daylight conditions. Any ramet that had failed to root was recorded and removed. Two of the successfully rooted ramets from each tray were chosen at random, and taken for subsequent determination of dry weights and mineral analyses of component parts (see below). From the remaining ramets, 15 were then chosen at random and rearranged in the supporting trays, in such a way that each adjoining cell to the module containing the ramet was empty. This thus formed a 'checkerboard' arrangement in the trays and ensured the modules were evenly spaced apart. The original randomised block design with 6 replications was maintained, although the physical arrangement of the blocks was changed, i.e. they formed a linear sequence along one bench in the glasshouse compartment. In mid March, ramets were repotted into 2 litre pots using standard peat compost (Westland, horticultural compost) and transferred to an unheated polythene tunnel. Dry matter distribution and cropping records were taken from these plants. Cropping records were taken from 20 plants from each ramet position (80 in total).

Analysis of Dry Matter Partitioning

Assessments of ramet dry matter distribution were carried out in the same way for each experiment, but the second experiment involved two phases of analysis. For the first experiment, runners were collected for assessments of growth and dry matter distribution at 4 to 5 week intervals, on 7 occasions through until March. Two ramets were removed from each tray (a total of 12 per treatment), to determine dry weights of the component plant parts, and for mineral and carbohydrate analyses. By March the plants were well established. In the second experiment additional ramets were destructively sampled at regular (four-weekly) intervals over the cropping season.

Plant Mineral Analyses

For mineral analyses of the crown and lamina tissues, the samples were ground to a fine powder, either using a pestle and mortar, or a microhammer mill; there was insufficient material for replicated analyses to be carried out on the roots and petioles. Samples were subjected to an acid digestion using sulphuric acid and hydrogen peroxide (Kjeldahl mixture), and a mixture of perchloric/nitric acids. The concentrations of the following elements were then determined: nitrogen, phosphorus and boron by colorimetry; potassium, calcium, magnesium, manganese, sodium, zinc, copper, and iron by atomic absorption or emission spectroscopy.

Mineral concentrations were also used to determine the total amount of a nutrient within the different plant parts. This was achieved by multiplying the concentration of the mineral by the amount of dry matter for the relevant plant part. These data were expressed in absolute terms as grams of mineral per plant part and as a percentage (%) of the total nutrient within the plant. The latter provides a description of the way a mineral is proportionally distributed throughout the entire plant.

Following mineral analyses, the samples (crown and lamina tissues only) were further extracted with perchloric acid, prior to analysis of the starch content by the iodine reaction, and were then hydrolysed in dilute hydrochloric acid, prior to the determination of the total 'hydrolysable'

carbohydrate content by colorimetry. The pH of the hydrochloric acid was optimised to extract primarily, only 'soluble' sugars such as glucose, fructose and sucrose.

Results

General Points

An assessment was made, in December, of ramet survival. Ramets from secondary, tertiary and quaternary positions had survival rates greater than 96%. The survival rate of primary ramets was, however, lower (90%), which correlates with their smaller total dry weight and perhaps more importantly their lower root dry weight.

Dry Matter Partitioning (experiment 1, vegetative establishment of ramets)

There was little obvious trend in the total dry weights of the ramets from the different ranks, when measured at the start of the experiment in October (Figure 99). There were significant differences between ramets for the dry weights of all the component parts: roots ($P<0.001$); crowns ($P<0.01$); petioles ($P<0.05$); laminas ($P<0.05$). In particular, there was a clear trend of root dry weight increasing as the age of ramet declined, i.e. the youngest ramets had the largest amount of root mass. When the dry weight distribution was expressed as a percentage of the total dry weight, there were clear differences in the partitioning to some of the component plant parts. This change in dry weight allocation with decreasing ramet age was particularly evident for the root as an increase allocation, and for the crowns as a decrease. The root component increased from <5% of the total dry weight for the primary ramets, to >25% for the quaternary ramets. There was a corresponding decrease in the crown tissue component.

The results of the ramets sampled in December, showed a significant ($P<0.001$) trend for increasing total dry weight of the ramets from the primary to quaternary positions (Figure 100). Again there were significant differences between ramets for the dry weights of all the component parts: roots ($P<0.010$); crowns ($P<0.05$); petioles ($P<0.05$); laminas ($P<0.05$). The most significant contribution to the observed increase in plant dry weight came from the roots, older ramets (primary and secondary in particularly) producing less root matter than the quaternary

ramets. However, there was little difference in the proportional partitioning of dry matter between the component parts for the different ramet positions.

The trend for increasing total dry weight was less apparent for the sample taken in January, although the quaternary ramets were significantly ($P<0.01$) larger in comparison to primary and secondary ranks. There were significant differences between ramets for the dry weights of the roots, petioles and laminas ($P<0.001$, $P<0.05$ and $P<0.05$ respectively). For both the primary and quaternary ramets the amount of total dry weight increased compared to the previous sampling date. The increase was, however, greater for the primary ramet than the quaternary. There was little change in total dry weight for the tertiary ramets over the last two sampling dates, while the dry weight for the secondary ramet declined, with the loss coming from mainly from crown tissue. Again, there was no apparent difference in the proportional partitioning of the dry matter between the component plant parts.

The results of the samples taken in February show the total dry weight of the primary ramets to be significantly ($P<0.01$) lower in comparison to other ranks. Of the component parts, the dry weights of both the roots ($P<0.001$) and laminas ($P<0.05$) of the primary ramets were significantly lower compared to the other positions. There was no apparent difference in the proportional partitioning of the dry matter between the component plant parts.

In samples taken in March, the total dry weight of the tertiary ramets was significantly ($P<0.01$) higher compared to other ranks. There were significant differences between ramets for the dry weights of crowns ($P<0.05$), petioles ($P<0.05$) and laminas ($P<0.05$). There was no apparent difference in the proportional partitioning of the dry matter between the component plant parts.

Results from the final samples taken in late March show that there were no significant differences in total dry weight between the four ramet positions (Figure 101). The only statistical difference recorded for the component parts was found with the roots, those of the primary ramets being significantly ($P<0.05$) smaller compared to the other positions. Again, there was no apparent difference in the proportional partitioning of the dry weight between the component plant parts.

Mineral Analysis from the October Sampling

Concentrations of nitrogen, phosphorus, potassium, calcium and magnesium were statistically different ($P<0.001$) with respect to both ramet position along the stolon and within the different plant parts within an individual ramet (see Figure 102 for crowns and laminas). Most of the other micronutrients measured, with the exception of copper, also showed statistically significant differences between ramet position and ramet plant part (Table 39). For calcium, magnesium, manganese, zinc and copper, the concentrations significantly ($P<0.001$) decreased, except for manganese in crown and zinc in lamina tissues, with decreasing ramet age.

For the first sampling, nitrogen and phosphorus concentrations were highest in the roots, followed by the laminas, crowns and petioles. The concentrations of nitrogen and phosphorus also increased along the stolon, i.e.the youngest ramets (quaternary) had the highest concentrations. As with nitrogen, potassium concentrations were highest in the roots, particularly with respect to quaternary ramet. This ramet had the highest concentration of potassium in all plant parts compared to its sister ramets. Concentrations of calcium were lowest in the laminas and highest in either roots or crowns. Calcium concentrations did, however, decline with ramet position; the youngest ramet (quaternary) had the lowest calcium concentration within all plant parts.

Calculations of the total amount of nitrogen, phosphorus and potassium within the plant show a very clear increase associated with a decrease in ramet age (see Figure 103 for nitrogen). The roots from the quaternary ramets had the highest concentrations followed by the tertiary and secondary ramets; the primary ramet always had the lowest. This pattern of mineral allocation was also clearly evident when these data were expressed relative to the total amount of a nutrient within the entire plant. The allocation of nitrogen, phosphorus, potassium, and calcium increased in the laminas, crowns and petioles and decreases in the roots as the ramet aged. The proportion of nitrogen, however, varied from around 15% in the laminas of quaternary ramets to 23% in primary ramets. While nitrogen in roots varied from just under 20% to 5% in the youngest and oldest ramets respectively.

Mineral Analysis from the December Sampling

Concentrations of nitrogen, phosphorus, potassium, calcium and magnesium by the time of the second sampling did not show any statistically significant differences with respect to ramet position. There were however, as with the first sampling, statistically significant differences ($P<0.001$) with respect to ramet plant part. Significant statistical differences in micronutrient concentrations were also evident, as with the first sampling, with respect to ramet position and ramet plant part (Table 40). There were, however, no differences in manganese and boron concentrations with respect to ramet position. In general, the concentrations of all the micronutrients measured increased with respect to the values obtained from the October sampling. For example, sodium concentration increased by around 5 times.

At the second sampling in December, roots no longer had the highest mineral concentrations as evident in the October sampling. The root concentrations of nitrogen and phosphorus in fact remained very similar to those in the first sampling, while the concentrations of these elements increased dramatically in other plant parts. In particular, the leaf laminas increased in nitrogen concentration over the first two sampling dates. Laminas had the highest concentrations of nitrogen and phosphorus of all the plant parts examined. Potassium concentrations measured at the second sampling were similar to those obtained in October with respect to the various plant parts, with the exception of the petioles. The concentration of potassium in petioles increased two-fold. Again, as was evident with nitrogen and phosphorus, roots no longer had the highest calcium concentration by the December sampling.

By the second sampling in December, the total amount of all nutrients measured within the various plant parts had increased, as would be expected, as growth increased dry matter production. As evident with the first sampling the total amount of the minerals, nitrogen, phosphorus, potassium, and calcium decreased in roots with ramet age. A similar decrease in mineral content was also apparent in leaf laminas at the December sampling. These data, when expressed relative to total plant mineral allocations showed little, if any, difference in the proportional distribution of nitrogen, phosphorus, potassium and calcium to ramet parts. Around 50% of the total plant nitrogen and phosphorus, for all ages of ramet, were in laminas and about 15-20% in the roots.

Mineral Analysis from the March Sampling

As with the second sampling, in December, statistical differences ($P<0.001$) in the concentrations of the major elements were confined to different ramet plant parts and not to different ramet positions. All the micronutrients measured showed significant differences with respect to ramet plant part and not ramet position (Table 41). Again, there were further increases in the concentrations of manganese and sodium compared with the analysis on material collected in December.

At the third sampling, the patterns of concentration difference for nitrogen, phosphorus and potassium, in different plant parts, were generally very similar to those obtained for the December sampling. For the calcium analyses, there were changes with respect to different plant parts; calcium concentration was generally higher in crowns, but by the March sampling was higher in petioles.

It was generally true, and particularly so for nitrogen and phosphorus, that the pattern of nutrient distribution and the proportional allocation to various ramet parts were similar in material sampled in March compared to that obtained from the December sampling. There was a slight trend again for allocation of minerals to increase in the laminas at the expense of the roots.

Carbohydrate Content

In October, a significant ($P<0.001$) trend for decreasing concentrations of starch in the leaf laminae from primary to quaternary position was recorded, but this was not evident with the crown tissues (Table 42). There were no significant differences in the concentrations of total carbohydrates. Analysis of tissue collected during the December sampling showed that total carbohydrate and starch concentrations varied significantly ($P=0.005$ and $P=0.041$) and ($P<0.001$ and $P<0.001$) for ramet age and plant part respectively (Table 43). There was a clear trend for starch and total carbohydrate concentrations to increase in the laminas, crowns and roots of quaternary ramets. Total carbohydrate was generally similar irrespective of plant part examined or age of ramet (Table 43).

As with the previous two sampling dates, in October and December, the total carbohydrate concentrations, for March (Table 44), were generally similar with respect to laminas, crowns and roots when comparing sampling dates. There were, however, significant differences ($P<0.001$ and $P=0.026$) and ($P<0.001$ and $P<0.001$) between ramet age and plant part respectively (Table 44). Again, as with the sampling carried out in December, starch concentration decreased with ramet age. Primary ramets appeared to store less carbohydrate (starch) than quaternary ramets, particularly when expressed on a total plant dry matter basis; the primary ramets were also still the smallest at the final sampling compared to the quaternary ramets.

Dry matter partitioning (experiment 2, vegetative establishment of ramets and cropping)

The initial measurements, made when the stolons were first planted, showed that younger ramets (quaternary ramets) were slightly smaller but had more root dry matter (Figure 104). By the time of the second sampling date in September, despite a significant increase in dry matter production, there was little treatment difference in total ramet dry weight or in the amount of dry matter allocated to root, crowns, petioles or laminas. Dry matter production continued to increase with time and at the next sampling date in November all the ramets had put on around another 0.5g of weight per plant. Again there was no obvious treatment differences. After November there was little increase in dry matter production with all treatments showing little growth until March. The plants sampled in March showed an increase in dry matter production of between 0.5 and 1.0g per plant, but again there was no significant treatment influence (Figure 105).

In the second half of this experiment a batch of ramets, collected at the same time, were retained for analysis of their cropping performance and their growth and dry matter partitioning. At the start of the cropping trial in April, all the ramets irrespective of treatment had doubled their weight since the March sampling (Figure 106). The tendency for the quaternary ramets to be slightly larger was still apparent in the sampling carried out in April. By mid-May all the ramets had again doubled they're size and increased to around 15g per plant; primary ramets were still slightly smaller (Figure 107). In early May there was clear evidence that the above ground dry matter was increasing at a greater rate than that in the roots. Again, by June 12 ramet size had doubled with ramets having a mean weight of between 35 to 42g. For all the subsequent

destructive samplings after June to the end of the experiment, in September, plant size increased and remained between 50 and 60g per plant (Figures 108 and 109). Throughout the cropping experiment there was no consistent difference in dry matter partitioning between ramets selected from different positions.

Fruit Production in Relation to Ramet Position

Throughout the experiment records of fruit production were taken. Crop production was assessed by picking ripe fruit, at least every two days per week; during maximum fruit production, fruit were sampled three times a week. Fruit collected was assigned to one of four classes (>35mm, 25 to 35mm, 22 to 25mm and waste) depending on size (diameter). The former two classes (>35mm and 25 to 35mm) constitute commercial class 1 fruit. Individual cropping records were kept for each plant within the cropping trial, and for each destructive sampling date the total number and weight of fruit within each size class was recorded.

The total number of fruit and the total weight of fruit produced from ramets from different positions along the stolon is shown for the 5 months of the trial (Figures 110 and 111). Initial production for June was around 5 fruit per plant, which doubled in July and trebled in August. Fruit number production was maintained in September, but as crop weight was declining it would appear that the fruit were getting smaller. By the October sampling, fruit number and fruit weight per plant were both declining; fruit number was higher in October than July, but fruit weight in these months was similar. Again this indicates that fruit quality was declining in the months of September and October.

More detailed analysis of fruit production in relation to fruit size class (see above for class descriptions) is shown in Figures 112 through 115. There were no obvious major differences in fruit production, at any sampling date, that could be related to the ramets original stolon position. Early fruit production was dominated by a small number of class 1 fruits and very little waste (Figures 112 and 115). As the season progressed, fruit in class 1 of the size 25 to 35mm dominated production (Figure 113). Mean fruit number per plant was around 15 fruits per 4-week period, which had a total weight of around 170g. By the August sampling the production of class 2 fruit had increased dramatically (Figure 114). This contributed to around 50g of class 2

fruit per plant per four weeks. A similar number and weight of class 2 fruit was collected for the rest of the cropping trial.

Discussion

When collected from the mother plant and prepared for propagation, the position of a ramet on the stolon can influence its "quality", with the older ramets having less roots and lower rooting potential compared to younger ramets. The younger quaternary ramets are rootier than their older siblings. This is particularly true, the later the removal of the stolons from the mother plants. Late season removal of stolons appears to positively influence the quaternary at the expense of the primary ramet. Material selected in the August clearly showed less leaf senescence in the primary ramet position. Commercial propagator's practice would be to initiate stolon selected early autumn in line with the timing of the second experiment described here.

The relationship between connected ramets and the mother plant, in regard to how resources are shared and the influence on ramet development, has been studied in the wild strawberry, Fragaria chiloensis (Alpert, 1986; Alpert and Mooney, 1986). These studies have shown that there is considerable physiological integration between ramets, with the potential for exchange of resources such as water and photosynthates, depending on environmental conditions. Thus, when water and light are plentiful, unrooted ramets may supply much of their own carbon, but under conditions of low water and/or light availability, this is imported along the stolon from rooted siblings.

For ramets collected in late autumn, the initial differences carry through to effect the subsequent establishment and early growth phases during propagation. Younger ramets establish more quickly and show increased growth compared to older ramets. Although, these trends become less obvious, and inconsistent, during subsequent development, the primary ramets tend to be smaller compared to younger ramets, throughout the propagation period. However, this effect was much less evident when stolons were cut from the mother plant in August. Differences in dry matter distribution were small and rapidly disappeared during ramet establishment. This experiment has shown the importance of ramet position, with respect to its sister ramets, in determining rooting behaviour when isolated from the mother plant. On removal from the mother plant, ramets which are closest to their mother are more shoot dominant, i.e. the amount

of dry matter allocated to leaves is greater for primary compared to quaternary ramets. For the younger ramets the situation is the opposite, here ramets are much more root orientated. The amount of dry matter partitioned to roots from quaternary ramets was much greater than that evident with primary ramets.

These differences between primary and quaternary ramets are not just restricted to dry matter allocation. Concentrations of nitrogen, phosphorus and potassium were all much greater in the roots of quaternary ramets. These differences in nutrient concentrations are clearly reflected in significantly larger proportional allocation of mineral to roots. This situation does not last, however, and eventually the apparent importance of roots declines and dry matter allocation to leaf area increases, as do nutrient concentrations and the amounts of nitrogen, phosphorus and potassium in above ground organs. By the time this has been achieved ramets have become rooted.

When taking into consideration the negative impact that late season removal of stolons can have on ramet quality, it can be concluded that a stolon collected early in the season, with 4 ramets, provides planting material of generally uniform quality with respect to dry matter distribution. The small differences in ramet size, if present, were generally lost once the ramets had established. It is equally true, if not more important, that position had little, if any, influence on the seasonal cropping performance or total crop.

We can conclude that early selection of stolon propagules (ramets) from the mother plant, will limit size (quality) differences and that any differences that are apparent have no marked influence on subsequent cropping performance. Ramets from stolon of this size and quality can all be used to achieve similar crop productivity.

Table 39: Effect of position of ramet on stolon on the initial minor mineral content of leaf lamina and crown tissues, measured in October

Mineral element	Ramet				
	Primary	Secondary	Tertiary	Quaternary	SED
Magnesium (%)					
lamina	0.33	0.23	0.20	0.16	
crown	0.47	0.34	0.29	0.25	0.036
Manganese (ppm)					
lamina	41.8	25.4	18.5	14.8	
crown	18.2	17.7	17.7	16.9	4.95
Sodium (ppm)					
lamina	258	268	251	348	
crown	385	509	826	783	96.1
Zinc (ppm)					
lamina	18.5	12.2	17.4	20.4	
crown	79.3	49.3	29.0	24.7	7.43
Copper (ppm)					
lamina	50.7	23.3	23.1	16.5	
crown	31.1	22.7	18.3	16.2	8.19

SED = standard error of difference (88 d.f.)

Table 40. Effect of position of ramet on the minor mineral content of leaf lamina and crown tissues, measured in December

Mineral element	Ramet				
	Primary	Secondary	Tertiary	Quaternary	SED
Magnesium (%)					
lamina	0.51	0.48	0.47	0.46	
crown	0.44	0.45	0.46	0.51	
root	0.86	1.04	1.00	0.98	0.526
Manganese (ppm)					
lamina	161.3	168.8	142.3	148.4	
crown	46.6	41.7	43.6	35.6	
root	54.8	42.4	43.8	41.7	16.22
Sodium (ppm)					
lamina	1641	1310	1518	1570	
crown	1487	1495	1661	1441	
root	1378	1222	1169	1123	108.0
Zinc (ppm)					
lamina	39.9	39.3	40.3	38.6	
crown	125.3	129.1	104.5	107.2	
root	142.4	79.5	63.2	47.3	13.52
Copper (ppm)					
lamina	10.0	8.1	6.6	7.1	
crown	153.2	156.2	126.6	129.3	
root	183.7	87.0	56.7	22.6	24.82

SED = standard error of difference (24 d.f.)

Table 41: Effect of position of ramet on the minor mineral content of leaf lamina and crown tissues, measured in March

Mineral element	Ramet				
	Primary	Secondary	Tertiary	Quaternary	SED
Magnesium (%)					
lamina	0.64	0.60	0.59	0.58	
crown	0.83	0.87	0.85	0.87	
root	0.71	0.68	0.72	0.66	0.041
Manganese (ppm)					
lamina	494.1	491.9	516.0	497.4	
crown	48.6	47.9	49.6	48.1	
root	85.4	87.1	90.1	83.3	27.17
Sodium (ppm)					
lamina	2541	2175	1651	2062	
crown	1281	1289	1304	1295	
root	1922	1997	1884	1673	249.5
Zinc (ppm)					
lamina	40.9	40.9	39.7	40.9	
crown	96.8	90.4	89.8	86.7	
root	71.5	68.7	69.5	62.6	5.66
Copper (ppm)					
lamina	6.0	5.7	5.4	5.1	
crown	30.4	29.9	26.7	22.5	
root	16.2	20.8	20.6	11.7	3.50

SED = standard error of difference (68 d.f.)

Table 42: Effect of position of ramet on stolon on the initial starch and total carbohydrate content (%) of leaf lamina and crown tissues, measured in October

	Ramet position on stolon			
	Primary	Secondary	Tertiary	Quaternary
Total carbohydrate				
Leaf lamina	40.9	45.9	42.2	42.5
Crown	36.9	39.9	36.6	38.8
Starch				
Leaf lamina	2.2	1.68	1.09	0.83
Crown	3.52	4.29	3.27	2.51
Soluble carbohydrate*				
Leaf lamina	38.9	44.2	41.1	41.7
Crown	33.4	35.6	33.3	36.3

*Note: The term soluble carbohydrate refers to hemicelluloses, and soluble carbohydrates such as sucrose, fructose and glucose.

Table 43: Effect of position of ramet on the starch and total carbohydrate content (%) of leaf lamina and crown tissues, measured in December

	Ramet				
	Primary	Secondary	Tertiary	Quaternary	SED
Total carbohydrate					
lamina	26.8	26.5	30.0	31.9	
crown	26.1	28.0	26.2	30.5	
root	29.9	35.8	29.2	31.8	2.02[a]
Starch					
lamina	0.3	0.4	0.3	0.7	
crown	2.7	2.4	2.1	4.3	
root	5.6	6.6	5.8	8.9	1.02[b]

SED = standard error of difference ([a] 18 d.f.; [b] 24 d.f.)

Table 44: Effect of position of ramet on the starch and total carbohydrate content (%) of leaf lamina and crown tissues, measured in March

	Ramet				
	Primary	Secondary	Tertiary	Quaternary	SED
Total carbohydrate					
lamina	26.0	28.4	29.6	30.5	
crown	31.9	33.2	34.0	35.7	
root	29.4	31.6	32.9	33.7	1.55
Starch					
lamina	0.5	0.8	0.9	0.8	
crown	9.0	12.3	12.4	13.5	
root	3.6	6.2	6.5	6.9	1.24

SED = standard error of difference (68 d.f.)

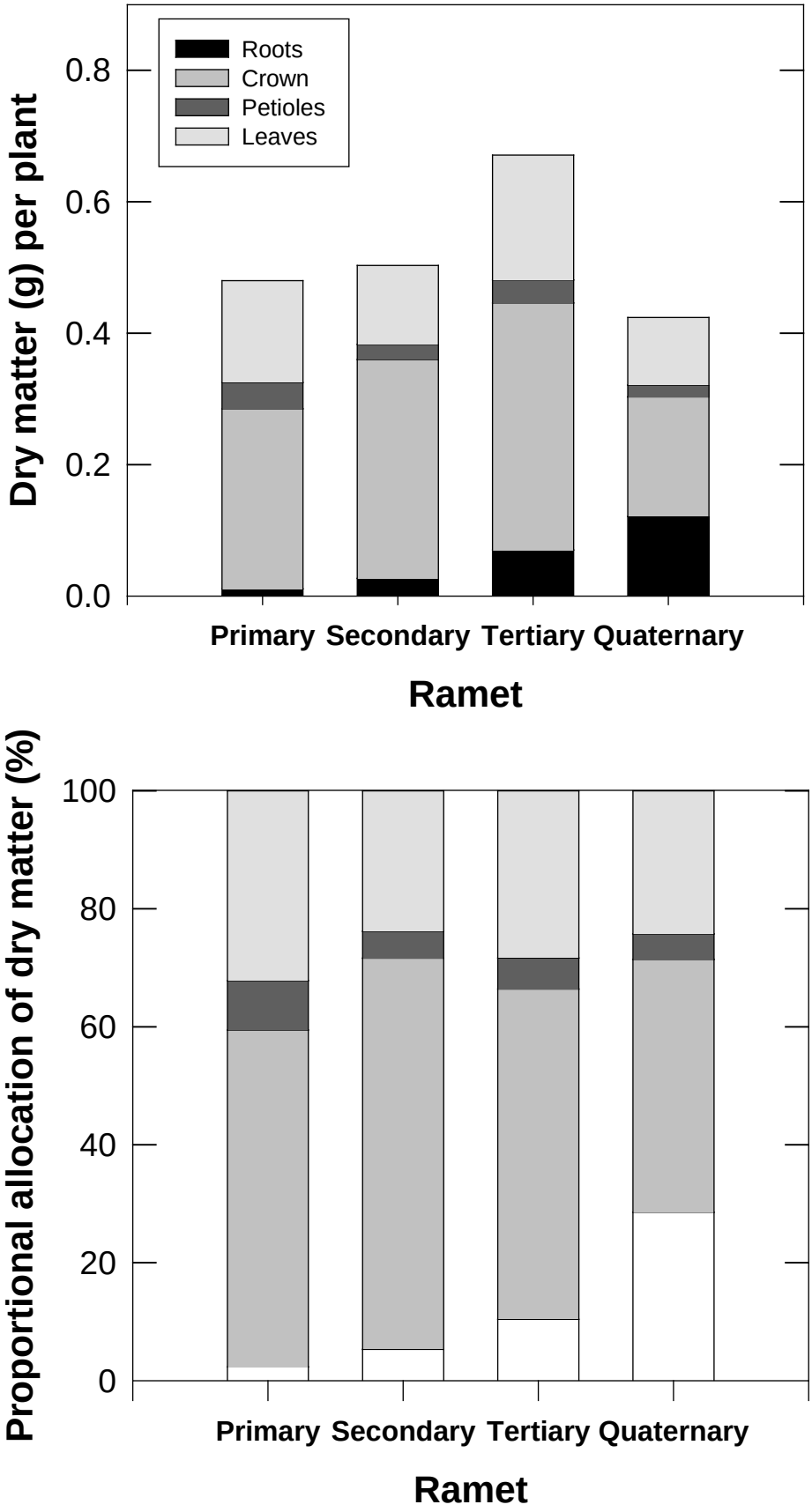
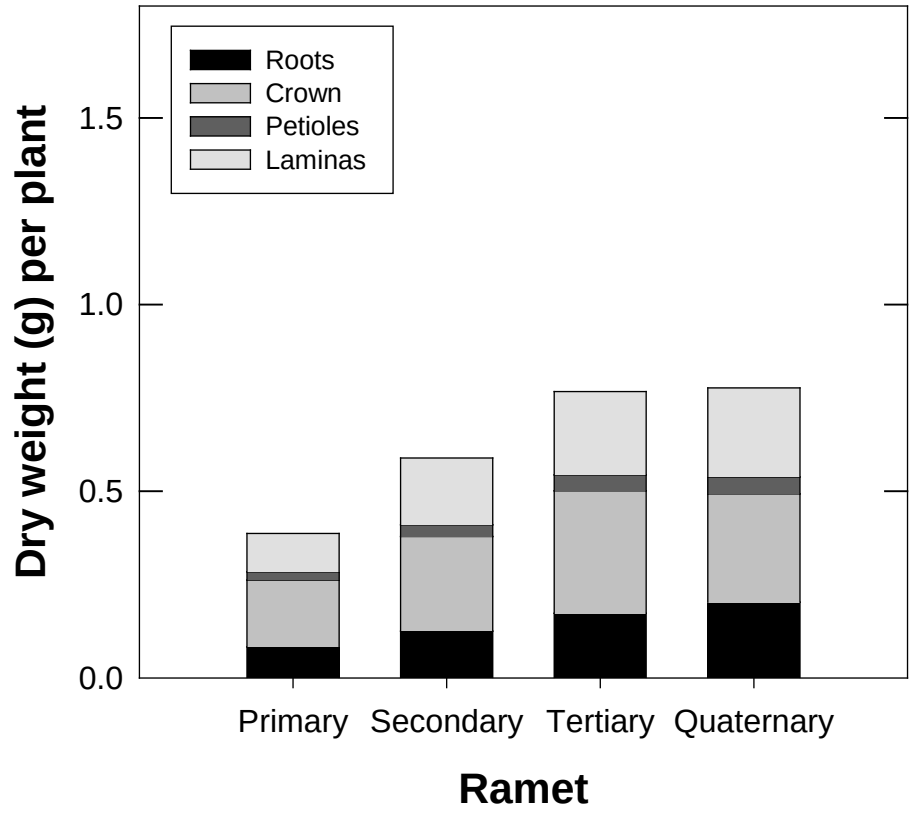


Figure 99: Difference in dry weight of ramets along a strawberry stolon expressed as either, total dry weight (a), or proportional allocation of dry matter (b) of plants sampled in October



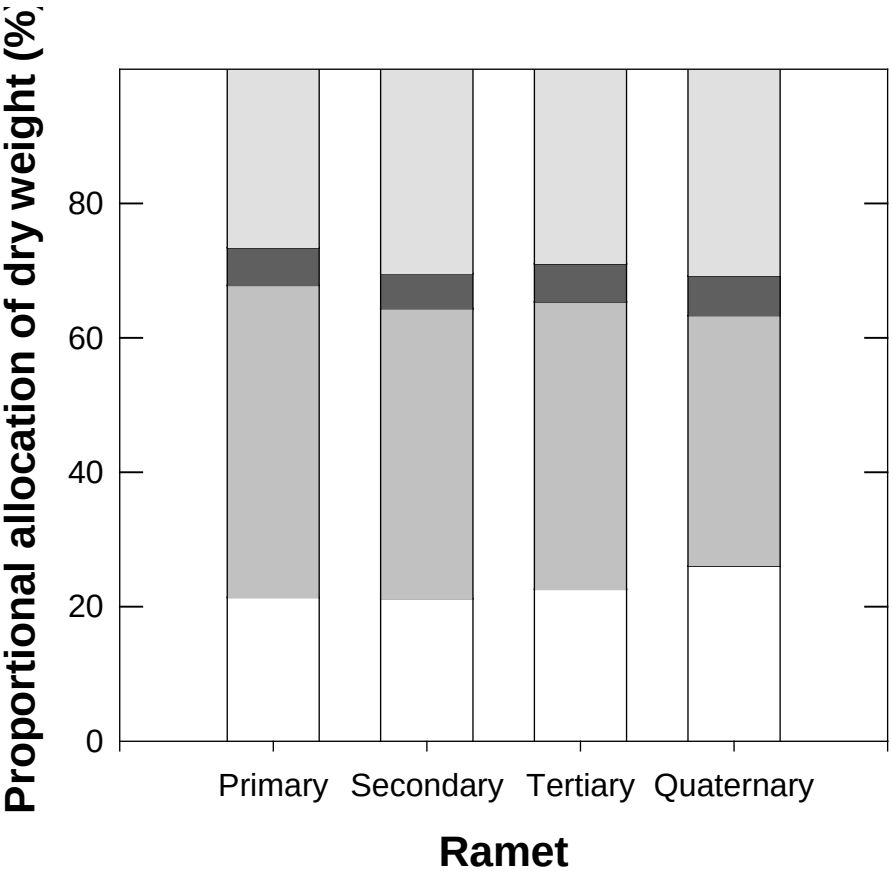
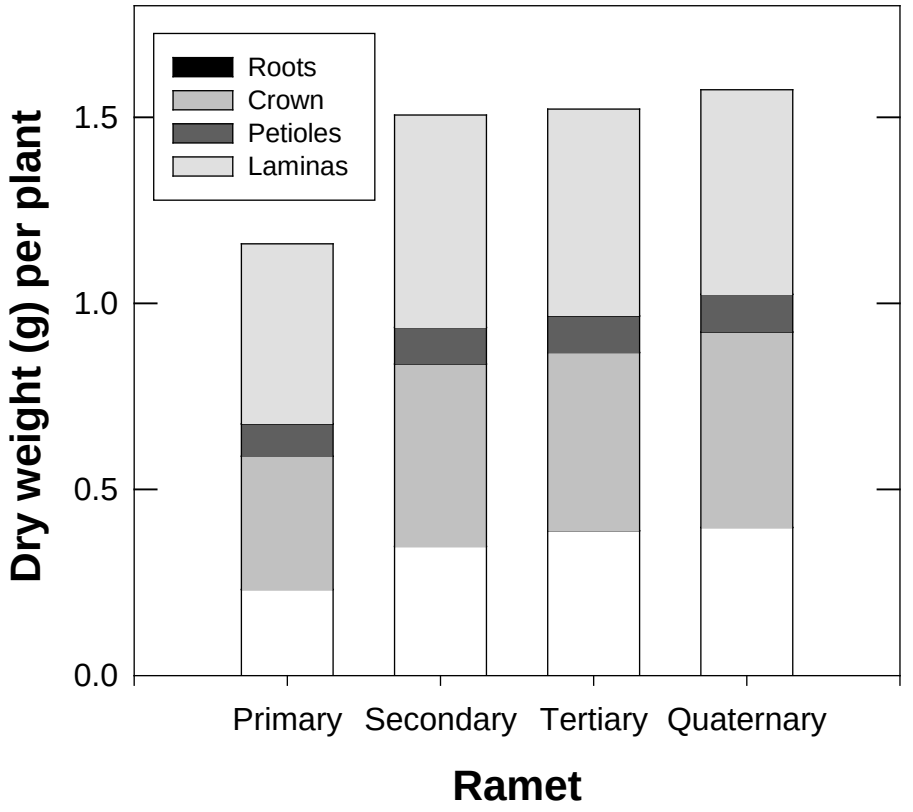


Figure 100: Difference in dry weight of ramets along a strawberry stolon expressed as either, total dry weight (a), or proportional allocation of dry matter (b) of plants sampled in December



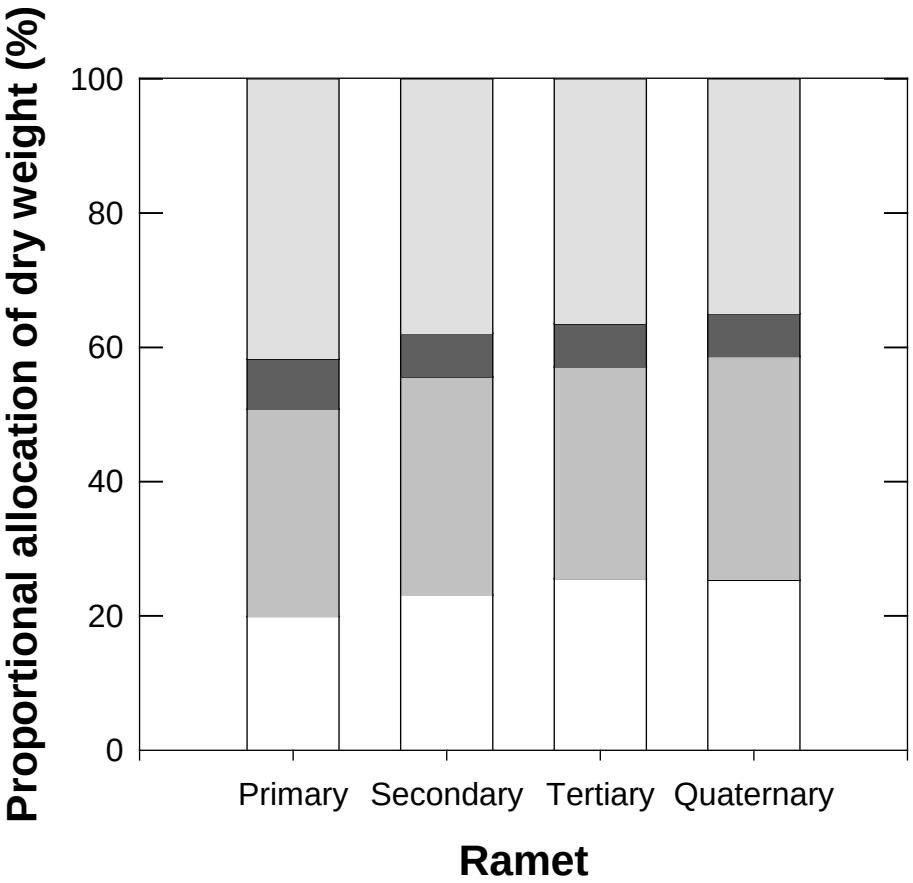


Figure 101: Difference in dry weight of ramets along a strawberry stolon expressed as either, total dry weight (a), or proportional allocation of dry matter (b) of plants sampled in March

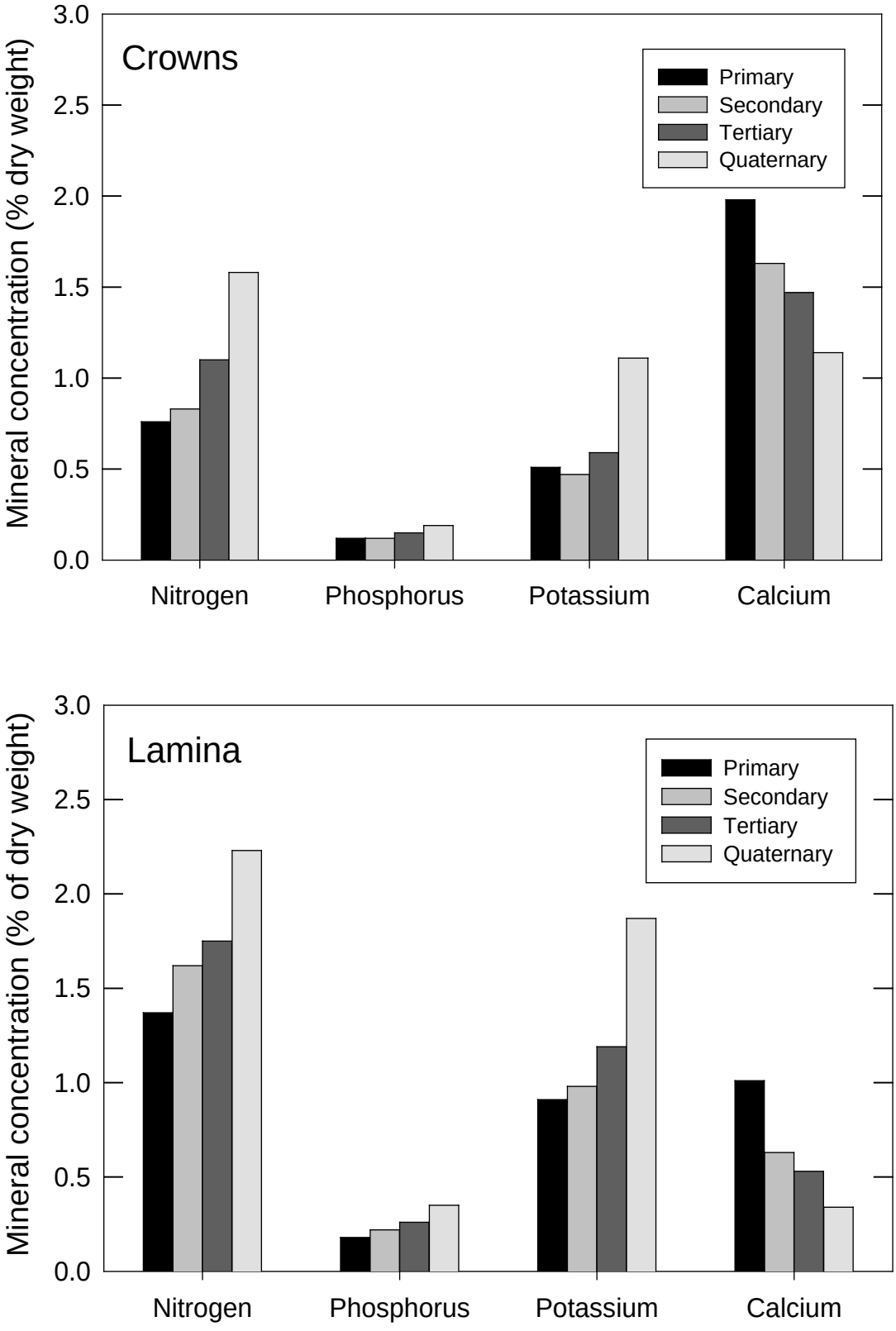
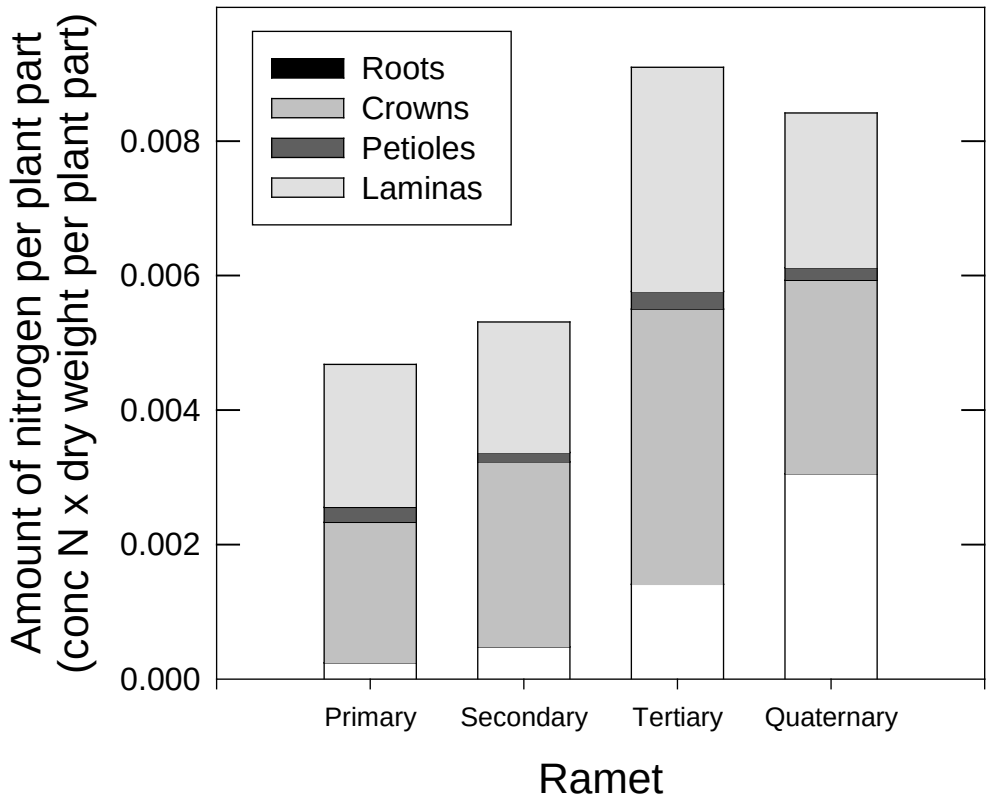


Figure 102: Difference in the mineral concentrations (nitrogen, phosphorus, potassium and calcium) of ramets along a strawberry stolon in either the lamina, or the crown of plants sampled in October



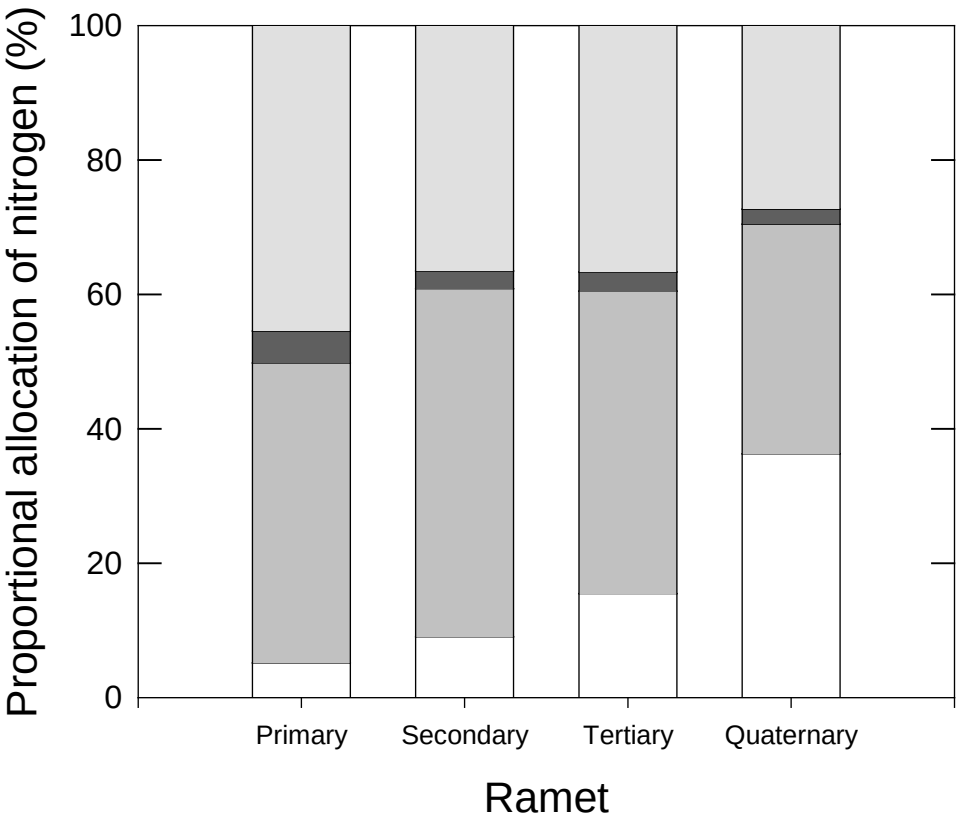


Figure 103: Differences in the amount of nitrogen per plant part and the proportional allocation of nitrogen to the roots, crowns, petioles and lamina of ramets sampled in October

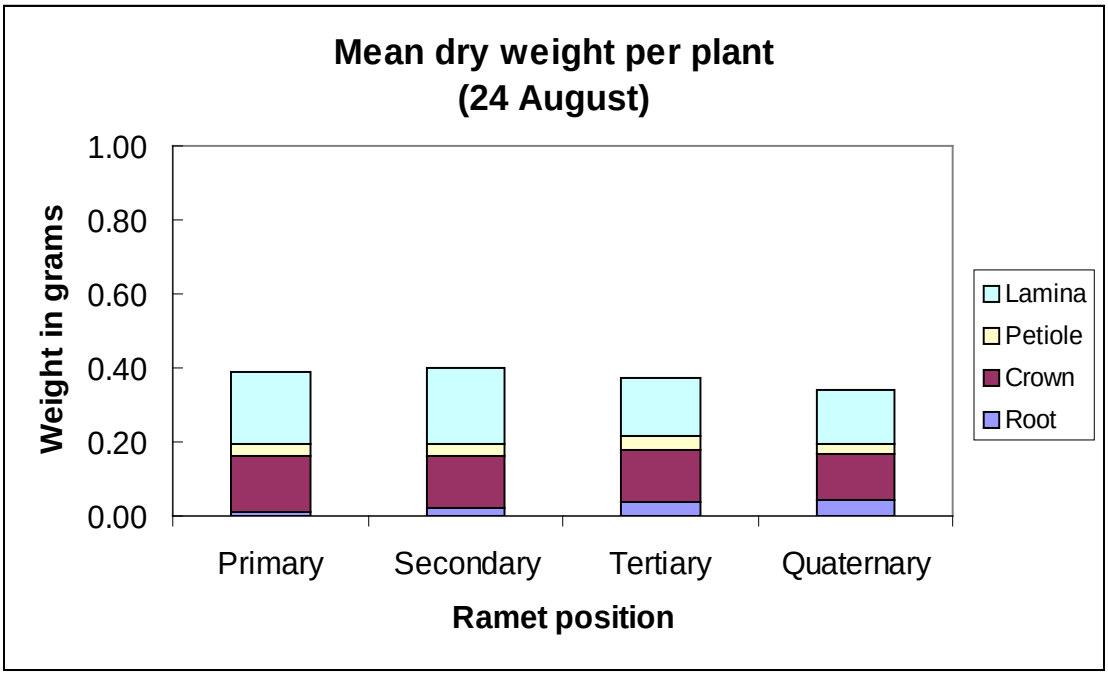


Figure 104: Dry matter distribution to roots, crowns, petioles and laminas of Everest ramets from different positions along the propagating stolon, at the start of the experiment.

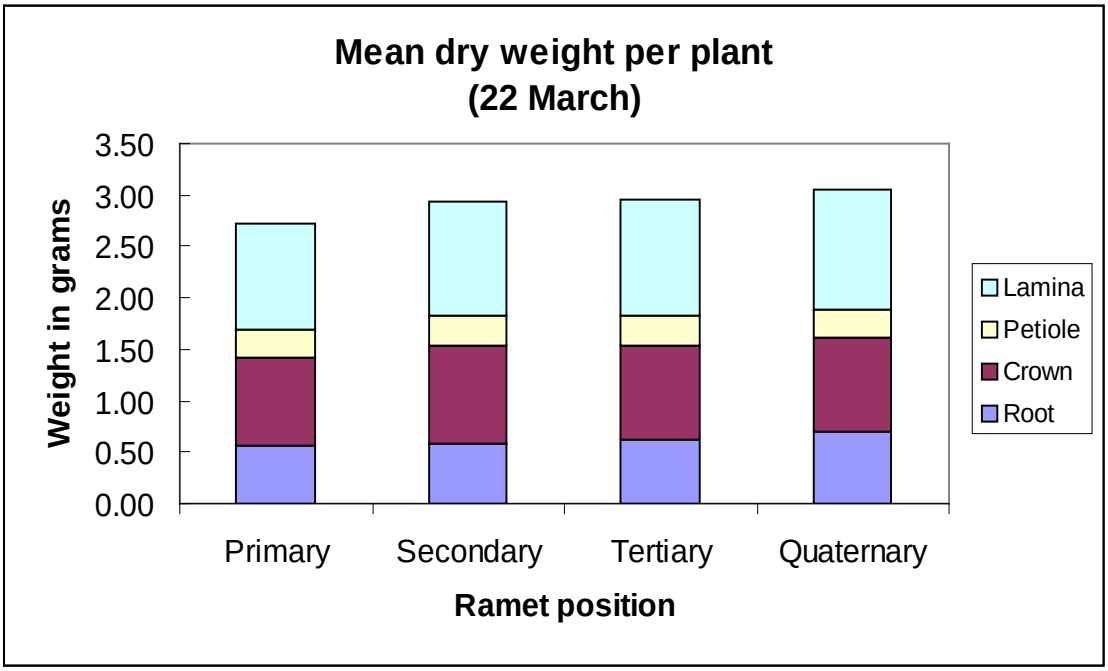


Figure 105: Dry matter distribution to roots, crowns, petioles and laminas of Everest ramets from different positions along the propagating stolon, on 22 March.

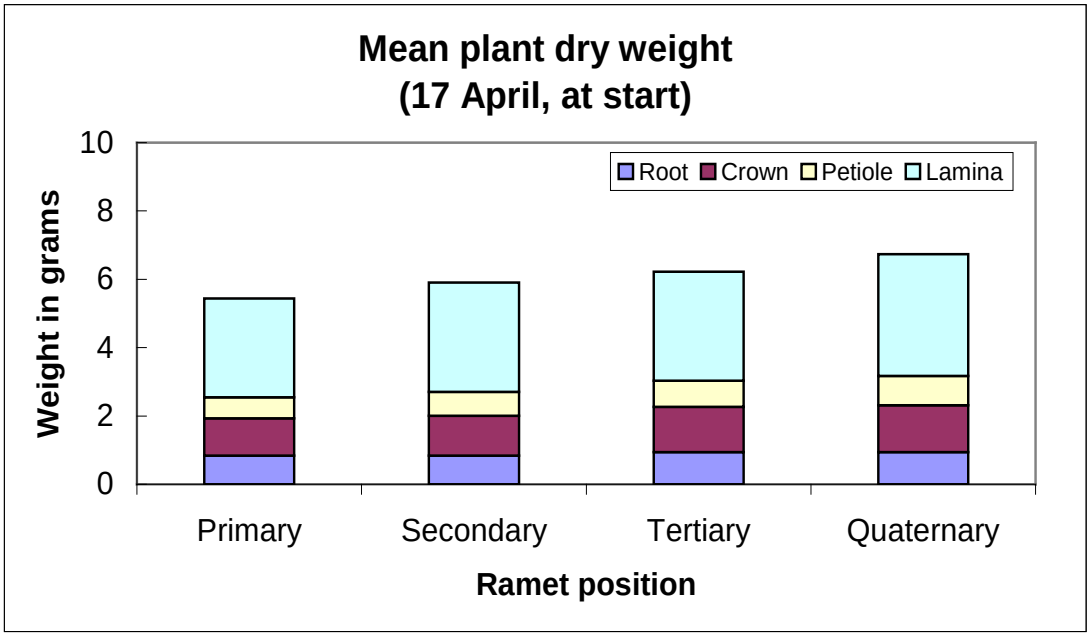


Figure 106: The mean dry weight and distribution of dry matter (at the start of the experiment) to roots, crowns, petioles and laminas of Everest ramets removed from different positions along the propagating stolon**.**

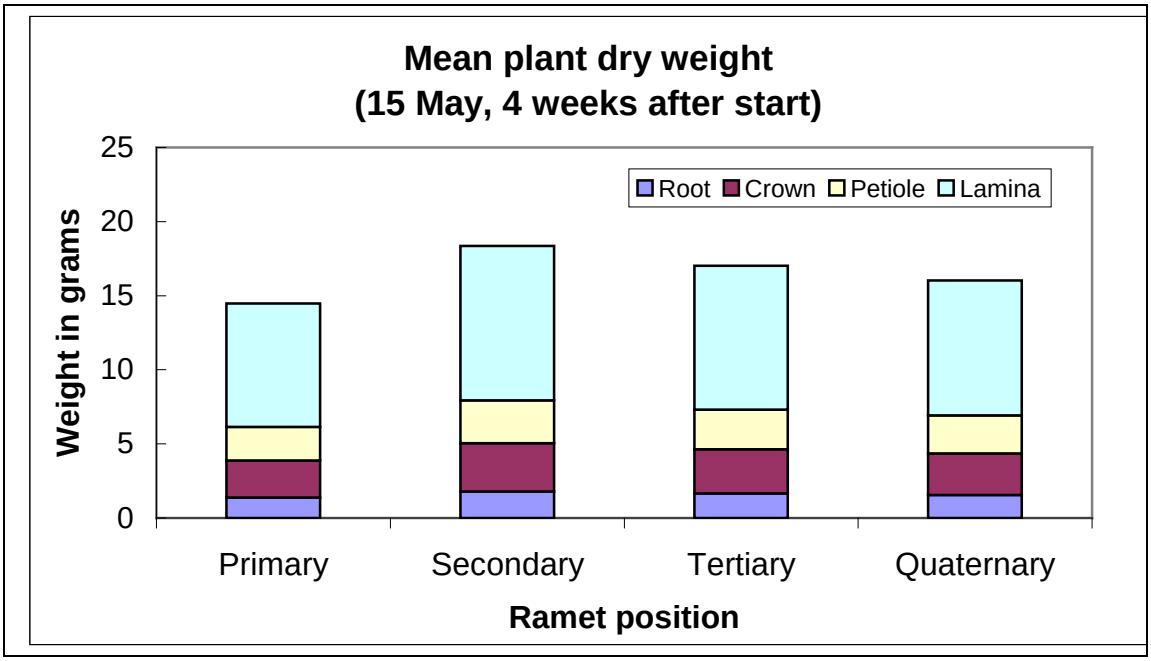


Figure 107: The mean dry weight and distribution of dry matter (after 4 weeks) to roots, crowns, petioles and laminas of Everest ramets removed from different positions along the propagating stolon.

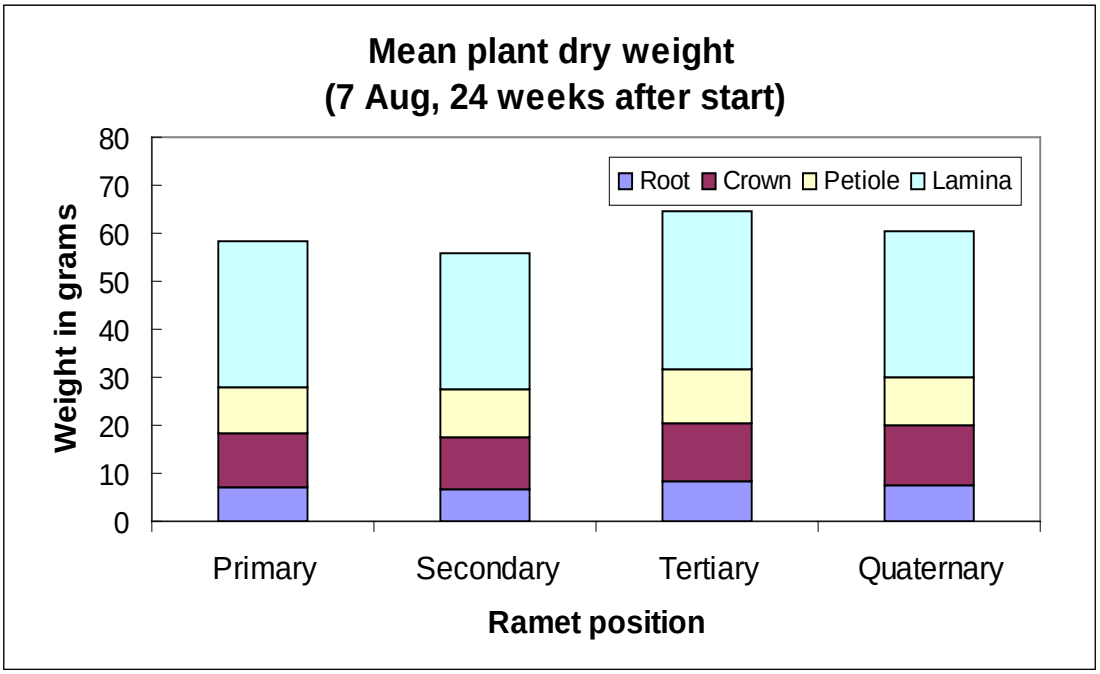


Figure 108: The mean dry weight and distribution of dry matter (after 24 weeks) to roots, crowns, petioles and laminas of Everest ramets removed from different positions along the propagating stolon.

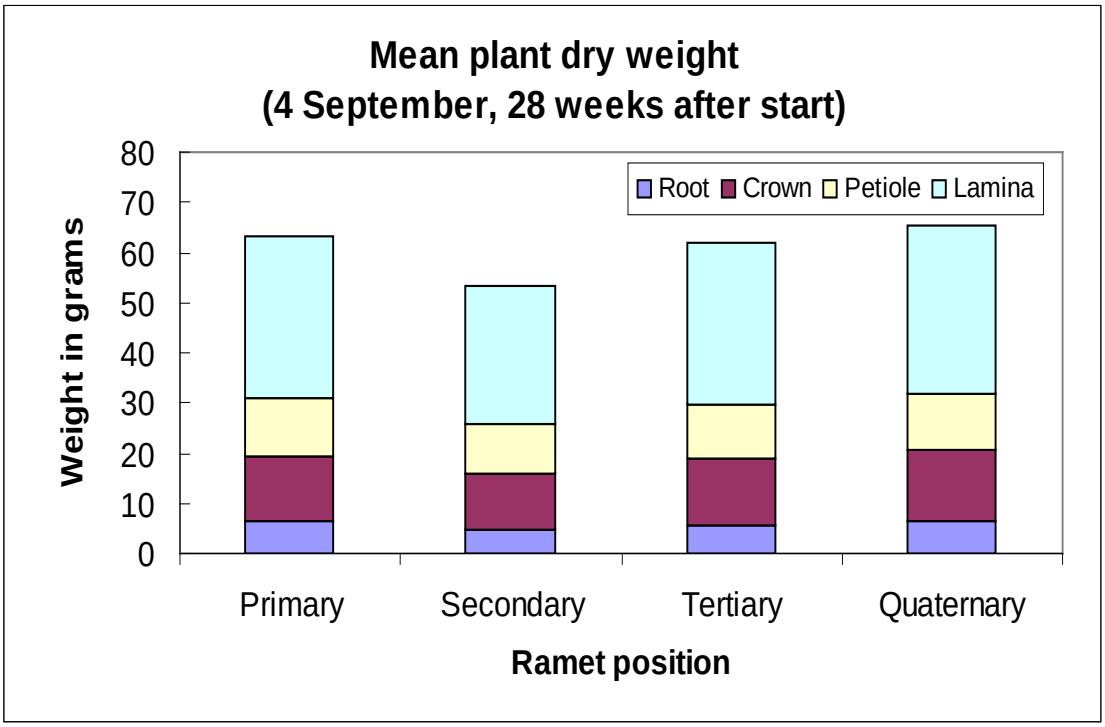


Figure 109: The mean dry weight and distribution of dry matter (after 28 weeks) to roots, crowns, petioles and laminas of Everest ramets removed from different positions along the propagating stolon.

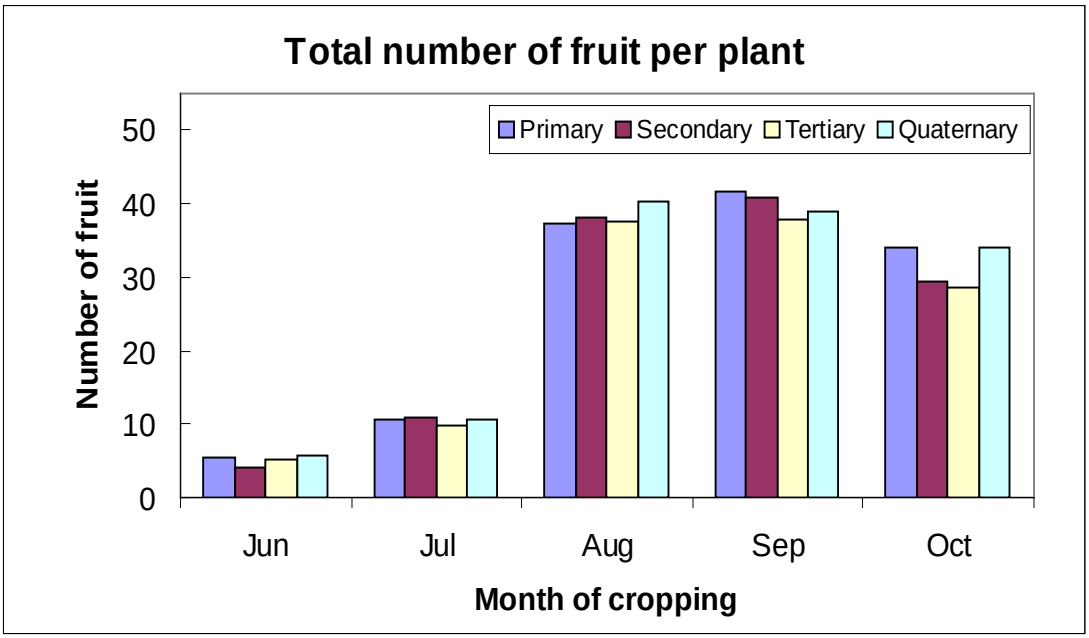


Figure 110 Total number of fruit (all classes) per plant recorded from July through to October 2001 for ramets of Everest plants from different original positions along the propagation stolon

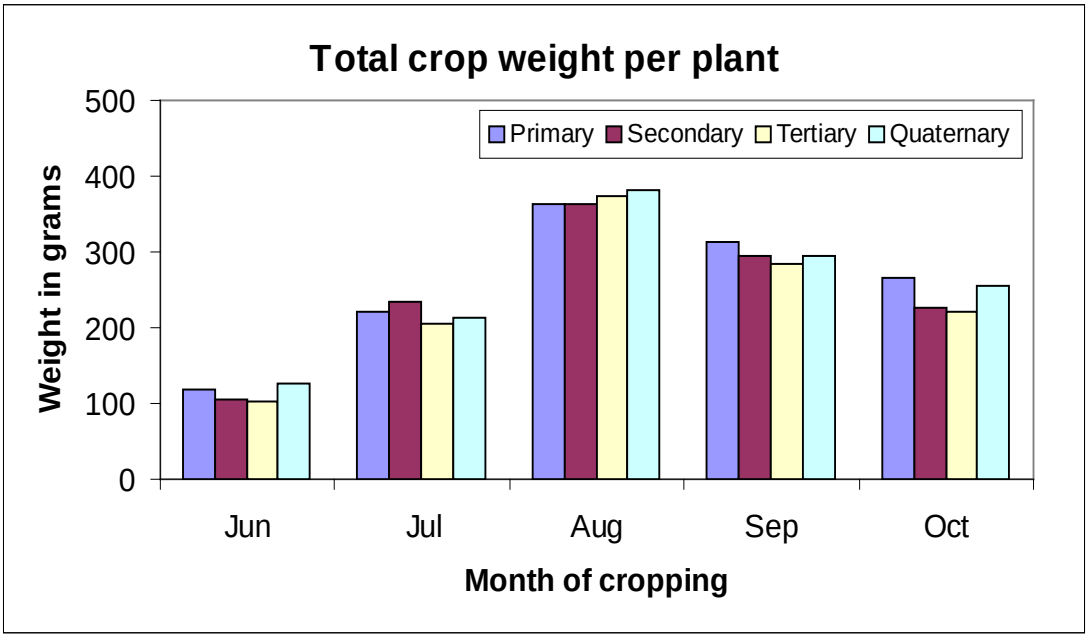


Figure 111: Mean fruit weight (all classes) per plant recorded from July through to October 2001 for ramets of Everest plants from different original positions along the propagation stolon.

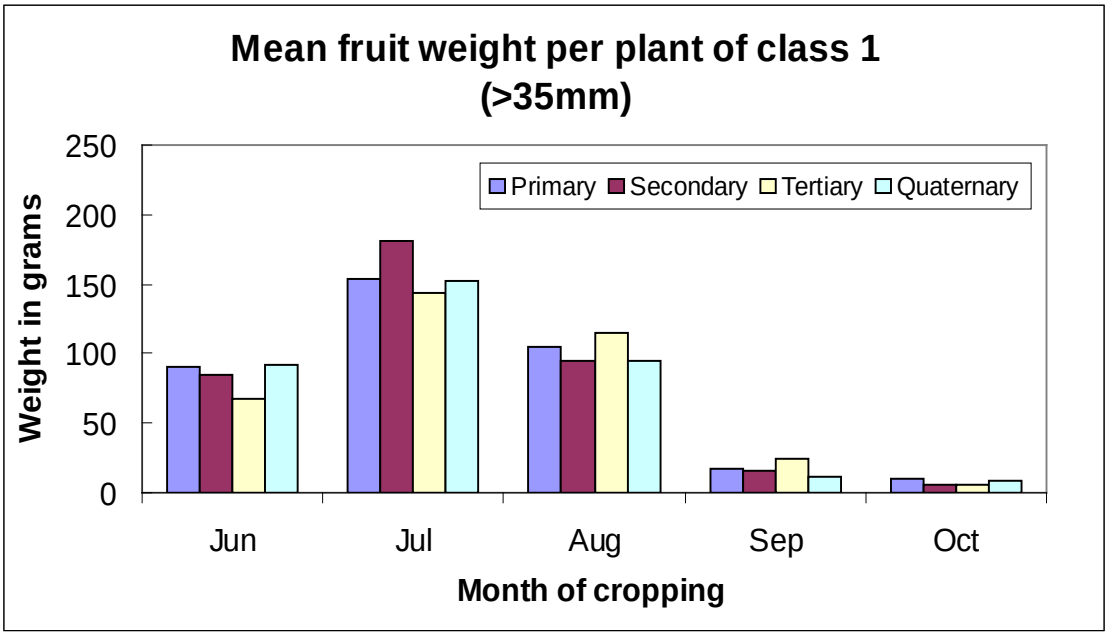


Figure 112: Mean weight per plant of class 1 (>35mm) fruit recorded from July through to October 2001 for ramets of Everest plants from different original locations along the propagation stolon

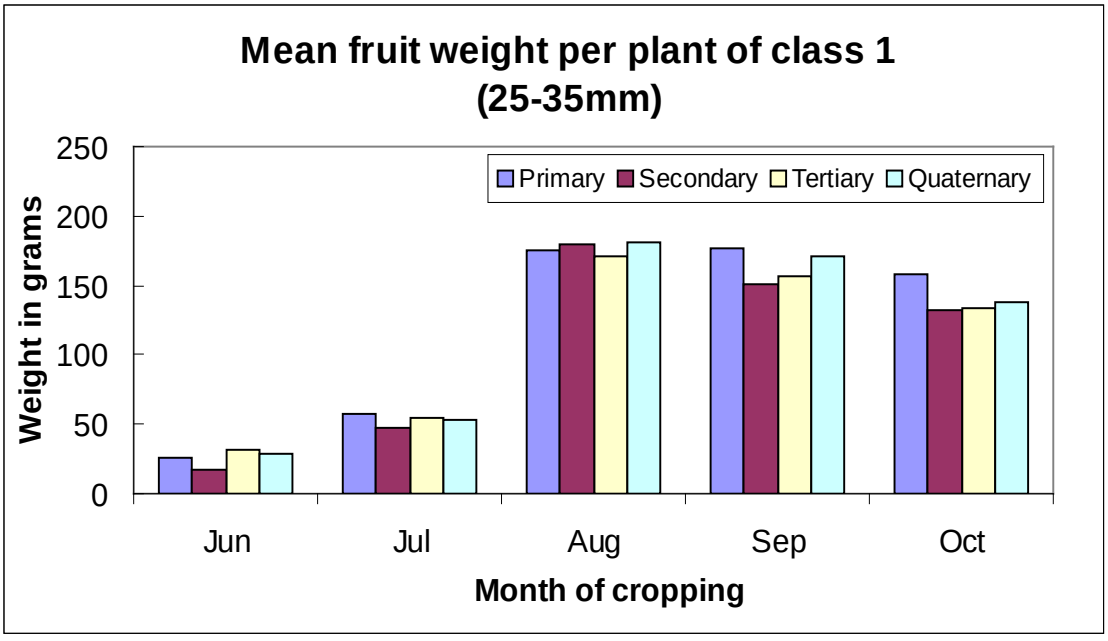


Figure 113 Mean weight per plant of class 1 (25 to <35mm) fruit recorded from July through to October 2001 for ramets of Everest plants of different original locations along the propagation stolon

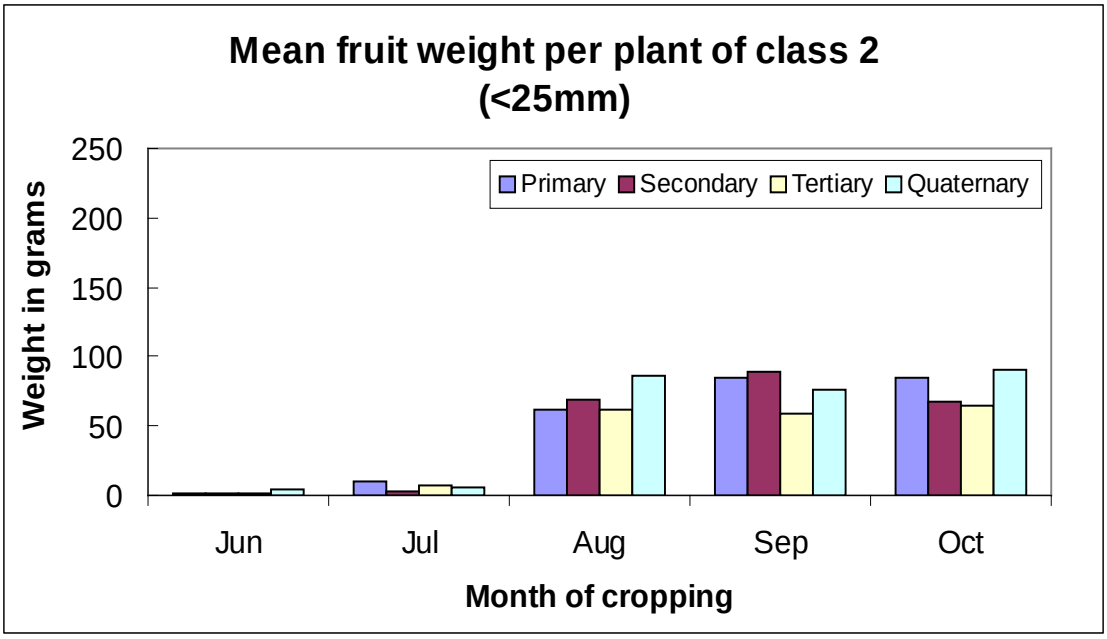


Figure 114: Mean weight per plant of class 2 (<25mm) fruit recorded from July through to October 2001 for ramets of Everest plants from different original locations along the propagation stolon

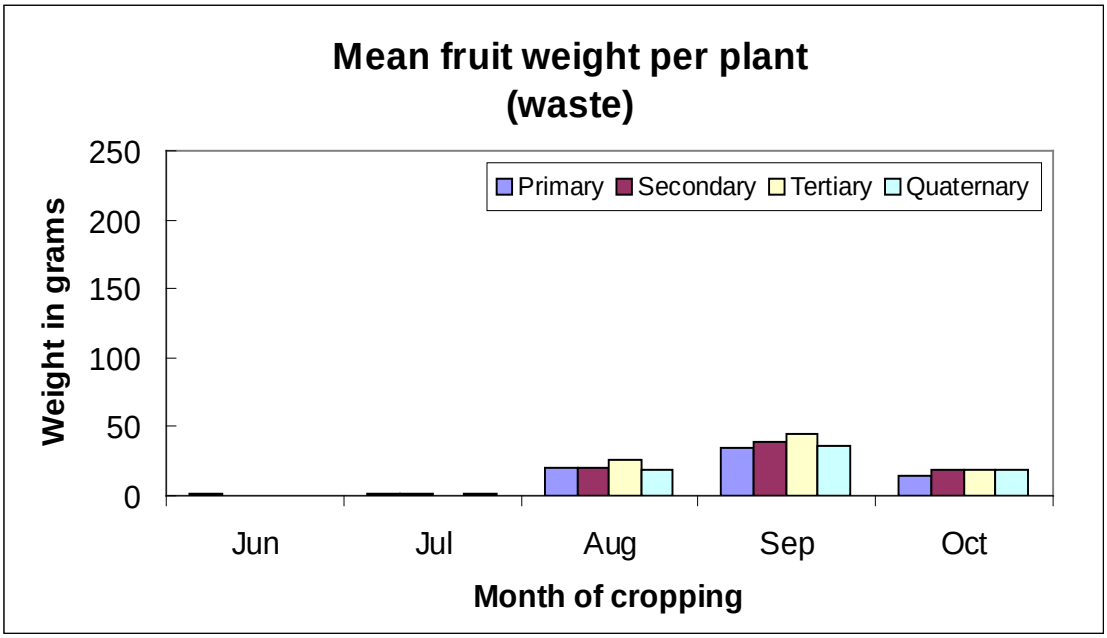


Figure 115: Mean weight per plant of waste (unmarketable) fruit recorded from July through to October 2001 for ramets of Everest plants from different original locations along the propagation stolon

MILESTONES

Objective 1

Number	Milestone	Completion Date
1.1.1	Complete analyses for electronic system for controlled water stress.	May 2000
1.2.1	Establish experiment on the effects of environment on everbearer production	March 2000
1.2.2	Complete data collection on the effects of environment on everbearer production	December 2000
1.2.3	Construct preliminary model to describe environmental effects on everbearer production	March 2001
1.3.1	Define flavour profiles for cvs. Everest and Elsanta	November 2000
1.4.1	Complete analysis relating flavour components to flavour profile	November 2000
1.5.1	Establish experiment to study the effects of water stress on flavour expression	March 2000
1.5.2	Complete study relating water stress to flavour perception	December 2000
1.6.1	Establish experiment on induction of two flowering periods in cv. Elsanta	January 2001
1.6.2	Collect flower initiation records in experiment determining the utility of spring flower initiation for extending the Junebearer season	April 2001
1.6.3	Complete evaluation of the utility of spring flower initiation for extending the Junebearer season	November 2001
1.7.1	Plant glasshouse experiment to validate everbearer growth model and establish resource partitioning patterns	March 2001
1.7.2	Complete data collection for everbearer growth model validation	October 2001
1.7.3	Complete analysis of everbearer growth model validation data and complete preliminary resource partitioning model	February 2002
1.8.1	Establish ADAS managed grower trials in SW Midlands and Kent for analysis of effects of water stress on flavour profile. ***Note -*** *the planned Kent trial was cancelled (as one grower industrial partner dropped out of the consortium). Two trials were conducted instead at Haygrove (SW Midlands) The first trial was an early crop (May-June) the second a late crop (October-December).*	July 2001

Number	Milestone	Completion Date
1.8.2	Complete analysis of data from two grower trials on effects of water stress at fruiting on strawberry flavour profile	November 2001
1.9.1	Establish experiment to test the effects of cultural/nutritional treatments on everbearer cropping and resource partitioning	March 2002
1.9.2	Begin application of cultural treatments to experiment on everbearer production in optimised temperature and light regimes	May 2002
1.9.3	Complete analysis of system performance of everbearers, in particular nutritional, environmental and cultural interactions	January 2003
1.10.1	***Note -*** *Work from previous years for both 'Elsanta' and 'Everest' had discounted water stress as a dominant factor in fruit flavour development. In view of the work on light integral it was agreed by the consortium to alter the scheduled commercial trial to test the hypothesis that solar irradiation incident on the ripening fruit would affect flavour expression therefore the Haygrove trial was altered accordingly and this task was revised and conducted alongside task 3.4 (see Interim Report – Year 3, page 42)* Develop and refine model relating fruit flavour to water stress - Establish ADAS managed experiment to investigate the influence solar radiation incident on ripening fruit	May 2003
1.10.2	Analyse data from the incident light experiment	March 2003
1.11.1	Establish experiment for model validation and monitoring in optimised growing system at Reading	February 2003
1.11.2	Apply cultural treatments to experiments validating performance of optimised everbearer growing system	May 2003
1.11.3	Complete analysis of performance of optimised everbearer growing system and robustness of the growth model	April 2004

Objective 2

Number	Milestone	Completion Date
2.1.1	Establish an experiment to investigate resource partitioning and fruit quality	*March 2001*
2.1.2	Complete experiment relating resource partitioning to fruit quality	September 2001
2.2.1	Establish further experiments to develop and refine the model relating fruit quality to resource partitioning	March 2002
2.2.2	Complete experiment to develop and refine the model relating resource partitioning to fruit quality	June 2002
2.3.1	*Evaluation of experimental findings at ADAS-grower sites - fruit quality aspects.* ***Note** - This task was covered by a single, revised milestone in year 4 alongside task 3.5 (see the minutes of the Consortium Meeting held on 04 December 2002)* Establish ADAS-managed trials in SW Midlands and Cambridgeshire for evaluation of optimised growing system	August 2003
2.3.2	**Note –** This task was revised in year 4 and re-numbered 3.5.2 - Complete analysis of performance of growing medium	January 2004

Objective 3

Number	Milestone	Completion Date
3.1.1	Complete growing system preliminary evaluation	*March 2000*
3.2.1	Establish glasshouse pot experiment to evaluate growth, development and fruiting in selected growing media	April 2000
3.2.2	Complete data collection evaluating plant performance in five different media	October 2000
3.2.3	Complete data analysis and select growing media for further evaluation	January 2001
3.3.1	Establish experiments in bags/troughs to determine growth, development and fruiting in selected growing media	March 2001
3.3.2	Analyse performance and select growing medium (or media) to be tested in model commercial systems	January 2002

Number	Milestone	Completion Date
3.4.1	***Note –*** *This milestone was revised in light of the revision made to task 1.10 and the decision to combine tasks 1.10 and 3.4 (see Interim Report – Year 3, page 42)* Establish ADAS-managed grower trials in SW Midlands and at ADAS Arthur Rickwood to relate defined water stress to fruit flavour and to evaluate the effects of growing media	May 2003
3.4.2	Complete analysis of performance of growing medium, its interaction with irrigation and nutrition, and agree modifications for final year ***Note -*** *Because milestone 3.4.1 (see above) had a later date than originally planned (agreed at the minutes of the Consortium Meeting held on 04 December 2002), it was not be possible to complete this milestone by the target date. The date for this milestone was changed from December 2002 to December 2003.*	December 2003
3.5.1	***Note -*** *This task was covered by a single, revised milestone in year 4 alongside task 2.3 (see the minutes of the Consortium Meeting held on 04 December 2002)* Establish ADAS-managed trials in SW Midlands and Cambridgeshire for evaluation of optimised growing system	August 2003
3.5.2	Complete analysis of performance of growing medium	January 2004

Objective 4

Number	Milestone	Completion Date
4.1.1	Plant out treated plants in controlled chilling of Junebearers experiment	*March 2000*
4.1.2	Complete experiment on controlled chilling for cropping period extension in cv. Elsanta	September 2000
4.1.3	Complete analysis of the use of controlled chilling for cropping period extension in Junebearers	November 2000
4.2.1	Establish experiment of treated plants to study the efffects of chilling on everbearer plant performance	March 2000
4.2.2	Complete data collection on the effects of chilling on everbearer plant performance	October 2000
4.2.3	Complete analysis of the use of controlled chilling on plant performance in everbearers	November 2000
4.3.1	Complete preliminary assessment of runner establishment	April 2000

Number	Milestone	Completion Date
4.3.2	Complete analysis of effects of runner variability on plant performance	December 2000
4.4.1	Establish experiment testing defined chilling treatments on everbearer cropping and testing the effects of runner variability	December 2000
4.4.2	Assess the effects of everbearer runner variability on runner performance	November 2001
4.5.1	Establish FAST-managed grower trial of cropping period extension for cv. 'Elsanta'	February 2002
4.5.2	Commence recording in experiment on Junebearer cropping period extension at the FAST managed grower trial	May 2002
4.5.3	Complete data analysis of experiment on Junebearer cropping period extension in the FAST-managed grower trial	February 2003
4.6.1	Establish experiments to optimise chilling treatments and analyse runner variability in everbearers	December 2001
4.6.2	Complete assessment of chilling and runner variability in everbearers	December 2002
4.7.1	**Note –** The milestones appertaining to Task 7 were changed in line with revisions made to this task. This was discussed and agreed by the consortium at their annual meeting in December 2002. It was decided to focus effort in 2003 on experiments to assess water delivery and additional nitrogen requirements in Everest in bags. Establish experiments for monitoring water use and nitrogen requirements of Everest plants in the new growing media, at East Malling	April 2003
4.7.1.1	Complete the collection of data associated with the water use and nitrogen requirements of Everest plants in the new growing media, at East Malling	September 2003

PUBLICATIONS AND CONFERENCE PROCEEDINGS RESULTING FROM THE PROJECT

Publications

ANGENENDT, A. and BATTEY, N.H. (2002). Model strawberry cropping. *HDC News*, **83**, 15-6.

ANGENENDT, A. and BATTEY, N.H. (2003). Everbearers: unravelling a myth. *HDC News*, **91**, 25-7..

ATKINSON C.J., LUCAS A.S., and TAYLOR D. (2002). Optimising everbearer plant performance prior to planting: effects of runner variability and chilling. *New Developments in the Soft Fruit Industry 2002*, Conference Proceedings 7-26.

ATKINSON, C.J., (2002). Programming for optimum cropping. *HDC News*, **84,** July, 15-17.

ATKINSON, C.J., (2002). Strawberry stolons: a life-line for resource sharing and communication. *Horticulture Research International Annual Report* for Year 2001-2003, 44p.

WATSON R., WRIGHT C.J., MCBURNEY T., TAYLOR A.J., and LINFORTH R.S.T. (2002). Influence of harvest date, and light integral on the development of strawberry flavour compounds. *Journal of Experimental Botany* **53**, 2121-2129.

WAGSTAFFE A. and BATTEY N.H. (2004). Analysis of shade and temperature effects on assimilate partitioning in the everbearing strawberry 'Everest' as the basis for optimised long-season fruit production. Submitted to the *Journal of Horticultural Science and Biotechnology*, January 2004.

WILTSHIRE, J.J.J. (2002). Strawberries - improved control of watering. *HDC News*, **No 87**, pp. 16-17.

WILTSHIRE. J. and HOLMES. S. (2003). Strawberry LINK Project: peat alternative substrates for strawberry crops grown in bags. *New Developments in the soft Fruit Industry*: Proceedings of the ADAS/EMRA/HRI Soft Fruit Conference, 25-26 November 2003, pp. 67-75.

WILTSHIRE, J.J.J. and HOLMES. S. (2004). Strawberries - you still can't beat peat. *HDC News,* **No 103**, pp. 21-23.

Forthcoming Publications

ATKINSON C.J. and LUCAS A.S. The impacts of reduced run-off on the growth and cropping of the everbearer 'Everest'.

ATKINSON, C.J., LUCAS, A.S. and Taylor, D.R. Implications of hierarchical position of strawberry stolon ramets on establishment, growth and cropping of 'Everest'.

ATKINSON, C.J., LUCAS, A.S. and TAYLOR, D.R. Determination of the chilling requirements of the everbearers 'Bolero' and 'Everest'

WAGSTAFFE A. and BATTEY N.H. (2004) Analysis of thermo-dormancy in the everbearing strawberry 'Everest': patterns of flower initiation, flowering and fruiting in relation to temperature and photoperiod. To be submitted to *Plant Cell Environment*.

WAGSTAFFE A. and BATTEY N.H. (2004) Modelling yield patterns in the everbearing strawberry 'Everest' as a tool for optimised long-season fruit production. To be submitted to the *Journal of Horticultural Science and Biotechnology*.

Conference Presentations and Proceedings

A poster was presented at the Horticulture LINK in Focus meetings held in London in February 2003 and February 2004.

Several presentations were given by the Scientific Partners of this HortLINK project at the ADAS/EMRA/HRI Soft Fruit Conferences between 2001 and 2003 including:

Strawberry substrates and everbearer growth model. Presentation at the ADAS/EMRA/HRI Soft Fruit Conference, November 27-28, 2001 at the Ashford International Hotel.

Optimising everbearer plant performance prior to planting: effects of runner variability and chilling. Presentation at the ADAS/EMRA/HRI Soft Fruit Conference, November 26-27, 2002 at the Ashford International Hotel.

Peat alternative substrates for strawberry crops grown in bags. Presentation at the ADAS/EMRA/HRI Soft Fruit Conference, November 25-26, 2003 at the Ashford International Hotel.

An abstract has been accepted for inclusion in the conference proceedings of the 5th International Strawberry Symposium, Australia 2004. The title of the presentation will be: Finding a temperature optimum for optimised long-season cropping in the everbearing strawberry 'Everest'. Authors: Wagstaffe and Battey.

An article advertising the project was included in the MAFF Agriculture LINK newsletter (October 2000).

EXPLOITATION PLAN

Background

The consortium organised a meeting on Friday 19th March, 2004 to discuss the results of the project and produce an exploitation plan.

Given the diversity of the partners involved in this project and the different interests pertinent to individual business activities, considerable thought was given as to how the plan should be constructed.

It was agreed that the most appropriate way to formulate the plan was to deal with the results of the four project objectives in turn and identify areas which could be exploited in each. Each area of exploitation is relevant to different partners and is classified under the headings:

- Growers
- Industry
- Research & Development

Any areas falling under the grower group will involve the provision of information transfer through HDC and other publications to growers who pay a levy to HDC. This will ensure that strawberry growers adopt any new production technology, which has been developed in light of the research undertaken.

Those areas falling under the industry group include new technological advances, which will be developed for the commercial advantage of the industry partners concerned.

Areas which fall into the Research & Development group include potential future research projects which will be undertaken to further exploit some of the knowledge and technology which has been developed in the life of the project.

The Plan

Objective 1

Growers

- Provision of an **HDC** Fact Sheet for growers detailing the optimum propagation and production techniques for the variety Everest with details of the optimum growing conditions. Triggers for heat-induced cropping troughs (thermodormancy) will be explained and preventative methods discussed. This will be delivered to strawberry growers in December 2004.

Industry

- **BPI Agri** are working closely with **University of Reading** and plan to develop new and improved spectral filters for use in polythene clad tunnels to help to create an optimum environment for growing the variety Everest under protection. In recent years, temperatures have been above the optimum for Everest with the result that growers have not achieved the full yield potential from this variety. Spectral filters that reduce temperatures during the growing season would therefore benefit strawberry growers who produce Everest under protection (including those marketing through **KG Fruits** and **WorldWide Fruits**). **BPI Agri** have started by conducting a desk study to assess the financial feasibility of producing such spectral filters.

Research & Development

- Further investigation into thermodormancy in Everest. The **University of Reading** have submitted a proposal to the **HDC** for a three-year PhD project. At present, heat induced cropping troughs can reduce commercial everbearing strawberry yields by 30% (Grower, Week 34 2003). The project aims to gain deeper insight into the physiological processes leading to thermodormancy. A comparison between Everest and two further everbearing

cultivars of commercial importance will enable direct comparisons at key stages of growth (i.e., flower induction and initiation, flowering and fruiting). This will aid the increased production of everbearing strawberry varieties by the UK soft fruit industry to exploit the lucrative out-of-season market. Partners who will benefit directly from this work include **ADAS Consulting Ltd**, **Farm Advisory Services Team Ltd**, **Nuclear Stock Association Ltd**, **KG Fruits Ltd**, **WorldWide Fruits**, **Edward Vinson Ltd**, **Haygrove Fruit** and all strawberry growers who pay a levy to **HDC**.

- There is the potential to develop a tool or model to predict the risk of thermodormancy based on relative growth rates in Everest and long-range weather forecasts. This work would be combined between industry and science partners. **ADAS** and East Malling Research (formerly **HRI**) are currently in discussion with **HDC** about developing a LINK project which might incorporate such a development.

- A three-year project is currently being finalised under the Rural Economy and Land Use Programme (RELU), which will employ a post-doctoral research fellow and a technician to study 'Implications of a Nutrition Driven Food Policy for Land Use and the Rural Environment'. Detailed analyses of the potential of plastics (spectral filters) for the control and manipulation of strawberry, raspberry and blackcurrant growth will be made. This will allow previous work on strawberries to be developed. **BPI Agri** will benefit from this study, enabling them to identify those plastics worthy of further development in their business.

- Closely related to the RELU project will be the work conducted within a collaborative PhD studentship funded between the **University of Reading** (RETF scheme) and **BPI Agri**. The title of the project is: 'Analysis of Modified Irradiance Environment as a Major Influence on Secondary Products of Commercial Importance'. The PhD student and the post-doctoral research fellow (RELU) will make use of the new BioCentre, with state-of-the-art equipment for biochemical analysis. This will allow beneficial effects of light/temperature environments on strawberry fruit quality and nutritional value for human consumption to be studied. The results of this study will be of particular benefit to the supermarket partners in this LINK

project namely **Sainsbury's Supermarkets Ltd**, **Tesco Stores Ltd** and **Marks and Spencer Plc** as well as the marketing and grower organisations.

- Work was carried out in Objective 1 to develop a weighing system for transpiration and substrate moisture monitoring. It was demonstrated that it is possible to monitor water use by employing a weighing technique. Such a technique could be invaluable to growers who needed to exercise more control over the moisture content of their substrates, particularly given any future regulations regarding pollution caused be excessive feed run-off into the soil. However, it will take further work to refine the system before it can be used commercially. **ADAS**, East Malling Research (formerly **HRI**) and The **East Malling Trust for Horticultural Research** are currently examining the possibility of a potential LINK project to further develop this technique. This would involve the instrument manufacturer **Sensatech Ltd** and the trade supplier **Field Fumigation Ltd**. Any future technology of this kind would benefit the manufacturers as well as all strawberry growers.

Objective 2

Growers

- The provision of an **HDC** Fact Sheet informing growers on the components of strawberry flavour and how this can be maximised through irrigation and other means. This will be delivered to strawberry growers in December 2004.

Industry

- Work conducted by The **University of Nottingham** during this LINK project determined the key components that confer flavour to strawberries. The development of a novel technique to measure sugars and flavour compounds in fruit will be particularly useful for growers, consultants and supermarket technologists to assist them in the production of high quality strawberries. The **Universtiy of Nottingham** is currently in discussion with the supermarket partners of this project, **Sainsbury's Supermarkets Ltd**, **Tesco Stores Ltd** and **Marks and**

Spencer Plc as well as the scientific instrument manufacturer **Protimeter plc** about the possibility of developing such technology through a LINK project.

- Work conducted by The **University of Nottingham** and **ADAS** in this project illustrated that flavour is improved through maximum light interception by developing fruits. ADAS are preparing a concept note for consideration by the soft fruit panel of the HDC to secure funding to investigate novel techniques to improve light interception in bag grown crops.

Research & Development

- The **University of Nottingham** found that there is sometimes a huge variation in sugar levels between harvest dates in bag grown strawberries. There is future scope to further assess the reasons why levels vary so considerably and how this can be influenced. To date, no further proposals have been considered.

Objective 3

Industry

- There is potential to develop new technology to predict the water requirement and use in the non-peat substrates experimented with in this project.

- However, since this project was set up, horticultural industries have started to utilise wood fibre rather than the composted bark/loam or composted bark/green compost mixes that were used as alternative substrates to peat in this project.

- Wood fibre is showing great promise due to its consistent properties and it is a sustainable resource. This product was not available in 1999 or else it would have been included in the project. There is increasing use being made of peat reduced substrates whereby blends of peat and other substrates such as wood fibre are being employed.

- The work carried out on composted bark mixes in this project demonstrated that strawberries grow successfully in such substrates. This has sent a positive message to the substrate manufacturer **Edham Ltd** (Westland Horticulture). As a result of the work carried out in this project, they now have the confidence to offer reduced peat substrates such as peat/wood fibre substrates to the horticultural industries and in particular the strawberry industry. They are in the process of conducting their own studies on the potential for using peat/wood fibre substrates in the strawberry industry.

Research and Development

- There is scope for future research to assess the pollution issue caused by run-off from strawberry bags following drip-feeding. Work is needed to further refine the application methods of irrigation and feeds in new substrates to reduce the threat of run-off water. East Malling Research (formerly **HRI**) have recently embarked on a DEFRA open competition project (HH 3609 TX), which uses strawberry as a model plant to investigate the control of water and nitrogen delivery and the subsequent effect on yield, flavour, quality etc.

Objective 4

Grower

- The provision of an **HDC** Fact Sheet to inform growers of the optimum ways to propagate the variety Everest. This will be delivered to strawberry growers in December 2004.

Industry

- Work conducted in this project on winter-chilling and season extension in Elsanta showed scope for the use of field chilling to increase yields as a direct result of greater flower initiation. A combination of field chilling and night-break lighting, moreover, extended the cropping period for this Junebearer. Before these methods become financially viable to the industry it will be necessary, however, to adjust the technique to make it suitable for a large-

scale production system. The **University of Reading** is currently considering ways of further developing this technique in combination with industry and science partners, possibly through the Reading Soft Fruit Technology Group.

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