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Authentication

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

Signature……………………………………………………………………………

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Date…………

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Practical section for growers

Background

Currently in the UK, tomato growers who have cropped throughout the winter period have done so by pulling out plants early in order to replant in August or September, and in so doing lose some production during late summer. The technique of replacing the old root system with a new adventitious root system initiated from the existing layered stem allows the old haulm to be removed with a fruiting crop *in situ*. This technique would therefore enable continuous cropping throughout this period and beyond. Previous studies have shown that new roots will develop when the stem is enclosed in moist rockwool and that the old root system can be detached without destroying the remaining plant. Such new root systems can reduce plant losses because of lower levels of *Botrytis* infection compared with conventional cropping in the latter part of the growing season.

However, a new root system that utilises the technique of enclosing stems within two moist rockwool blocks is cumbersome and does potentially pose the threat of *Botrytis* infection. The use of hydrated gels to stimulate rooting from the stem may offer benefits through reduced *Botrytis* risk. In addition the transparent nature of the gel and tubing allows the progress of root development to be monitored and the possibility of more rapid rooting.

New root development may be enhanced by water stress and high light levels. Therefore in July with high light and high plant transpiration and the possibility of mild water deficit in the shoot, rooting from the stems could be stimulated. Such a sequence of events improves the capability of the plant for capturing water by increasing the size of the root system. In contrast, later in the season, when light levels are lower and the shoot demand for water has decreased then there may be a reduced requirement for the plant to initiate new roots.

The overall aim of the project was to quantify the agronomic and economic feasibility of extending the tomato cropping season through the production of a new root system from existing plants.

The new roots method

Supaplants Ltd. (Sheffield, Sheffield University, Western Bank, Sheffield, S10 2TN) provided the gel used to initiate new roots from the stems of the growing tomato plants. The gel consisted of special formulations of laponite with rooting hormones and nutrients and was coded '55'. The apparatus constructed to initiate rooting from tomato stems consisted of 10cm lengths of clear, flexible plastic tubing slit lengthways with a 5mm diameter hole at 90° to the slit. The cylinders were positioned around the stem and secured using 5cm wide sticky tape at either end. 70ml of gel was injected through the hole and in order to exclude light, a 10cm wide strip of black and white polythene sheet was wrapped around the cylinder with the black side innermost and secured with a piece of sticky tape. The root initiation vessels were located on stems just above the slab onto which they would make contact. Once the gel kit had been removed and the rooted stem had made contact with the rockwool slab it was secured and covered with plastic sheeting to promote high humidity conditions required for rooting. As soon as new roots had rooted into the slab the secured plastic sheeting was removed and the stem exposed to the lower ambient humidity. This was done to avoid potential problems of high humidity induced necrosis of the stem tissue close to the new root system.

Crop husbandry for establishing new roots

The conventional and new root crops were identical at the start of the experiment with a population density of 1.79 plants per m^2. This was increased, by taking a shoot on every plant, to 3.59 per m^2. The crops differed in their treatment when the new roots were established.

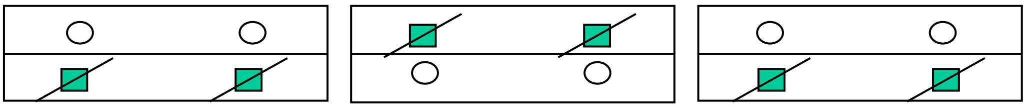


Diagram 1. The alternating new root slab () and old root slab () arrangement.

Pairs of rockwool slabs were set up parallel to each other, one providing substrate for original roots () and the other for new roots () for the second season of growth. The position of the 'old' and 'new' slabs was alternated (Diagram 1). Each slab supported four plants (before sideshoots), propagated in two plant cubes, and each slab was irrigated from six drippers. New roots established on the stems (after 2 weeks) made contact with rockwool slabs in the positions indicated by the circles. At this stage two of the 6 drippers were moved from the old slabs to the new slabs. The remaining drippers were moved across in stages according to new root establishment and sap flow data. The old root systems were detached from these plants once new roots had established (5 weeks). Typically 3-4 days later the old haulm was severed and removed from the glasshouse.

In the first week of September 2000, all of the heads in the conventional crop were stopped and 50% of heads were stopped in the new roots treatments (stems not rooted into new slabs). Once picking was complete from the stopped plants the haulm and old slabs were removed. New trusses appearing after the first week in September were pruned to 6 fruits, trusses appearing in October to December were pruned to four fruits. Subsequent truss pruning was undertaken according to truss strength. A new conventional crop was sown at the end of October 2000 and planted in November 2000 with a population density of 1.79 plants per m^2, matching that of the overwintered crop. Side shoots were routinely taken to produce a summer population of 3.59 per m^2 in both crops.

Summary of results

- New roots were successfully propagated from any position on the tomato stem that would allow the application of a gel (Supaplants Ltd., Sheffield University, Western Bank, Sheffield, S10 2TN) kit.
- Rooting success was similar whether gel kits were applied in July or August. Rooting was also achieved in November suggesting that in fact rooting from the stem is possible under low light conditions.
- Sufficient new roots were generated within the gel kits after 2 weeks to permit slab contact and growth into rockwool. Following slab contact and systematic removal of drippers from old and transfer to new slabs, it was another 5 weeks before the old root system could be safely detached.
- Plant losses when old roots were detached were 8 and 6 % for gel rooting kits applied at the end of July and August, respectively (year 1). Some of the losses were due to stem rotting and was an artifact of the high humidity conditions around the stem root junction required for successful re-rooting into new rockwool. It was found that these losses could be averted by the removal of high humidity conditions as soon as the new roots had established in the rockwool substrate.
- New root treatments produced continuous but relatively low yield during the winter period in November 2000 to March 2001 (see Table A; 2.59 to 1.23 kg per m^2), but the replanted conventional crop had out yielded the new root crop by 1.02 kg per m^2 in March 2001 (see Table A).
- Between March and September 2001 (year 2) the new root treatment experienced a loss in fruit quality, total and marketable yield through enhanced levels of blossom-end rot and uneven ripening compared with the control.
- Lower overall productivity may have been influenced by reduced leaf area in the new roots treatment in 2001 compared with the control.
- Cost benefit analysis showed a net loss of £6.99 per m^2 for the new roots compared with the conventional control crop (see Table B).

Table A. Yield differences and cost for conventional and new root crops. The cost per kg has been calculated for the mean price of size Grade D fruit for each month.

	Yield			**Price**	
Month	Control kg per m^2	New roots kg per m^2	diff kg per m^2	£ per kg	diff £ per m^2
Jun 2000	9.94	10.12	0.17	0.53	0.09
Jul	9.24	9.37	0.13	0.58	0.08
Aug	8.94	9.09	0.15	0.61	0.09
Sep	5.82	5.95	0.14	0.63	0.09
Oct	5.33	4.54	-0.79	0.74	-0.58
Nov	0.95	2.59	1.64	0.70	1.15
Dec 2000	0.00	1.53	1.53	0.75	1.15
Jan 2001	0.00	1.27	1.27	0.60	0.76
Feb	0.06	1.23	1.17	0.76	0.88
Mar	3.02	2.00	-1.02	0.91	-0.93
Apr	4.65	3.08	-1.58	0.77	-1.21
May	6.84	5.66	-1.18	0.66	-0.78
Jun	7.42	5.60	-1.82	0.57	-1.04
Jul	7.82	6.29	-1.53	0.59	-0.90
Aug	8.07	6.42	-1.66	0.58	-0.95
Sep 2001	5.70	4.76	-0.94	0.47	-0.44
Total	83.78	79.48	-4.30		-2.55

All labour is costed at £7.75 per hour and general crop work includes picking, training, de-leafing, spraying, pulling out and stringing new plants. There was minimal additional cost for the new root treatments for an extra week of CO_2 water and nutrients that has not been allowed for.

Table B. The cost of additional installation and crop management operations for the new root treatments compared with the conventional control cropping system.

		Treatment costs		
Operation	**Item**	Control £ per m^2	New roots 1 £ per m^2	New roots 2 £ per m^2
Materials	Gel kits 2000		1.69	1.69
	Gel kits 2001		0.85	0.85
	Plants	0.87		
	Gas (1 week)		0.19	0.19
Labour	Installing kits 2000		0.86	0.86
	Installing kits 2001		0.43	0.43
	Slab contact 2000		0.86	0.86
	Slab contact 2001		0.43	0.43
	Total	0.87	5.31	5.31

Action points for growers

- New roots can be initiated on the stems of tomato plants by the use of gel kits (from SupaPlants Ltd) at any time during the growing season. Within a single growing season this re-rooting technique does not alter yields compared with a conventional tomato crop.
- The new root technique could be used to bypass *Botrytis* lesions and maintain plant densities and therefore crop yields.
- It is not recommended that continued cropping of tomatoes should be attempted through the use of a new roots system alone.
- The successful extension of the tomato cropping season into late autumn and winter in the UK will require techniques that improves carbon fixation such as supplementary lighting.

Anticipated practical and financial benefits

This two-year project has provided growers with information on the agronomic and economic viability of growing a tomato crop for two years continuously (see Tables A and B). The overall conclusion from the work is that the new roots technique alone, is an uneconomic option for UK growers with which to maintain tomato production over the winter months and on into a second subsequent season.

The cost of the new roots system for continued cropping might be reduced with further development of the re-rooting technique using gel impregnated rockwool sleeves and alteration of the time of re-rooting to October/November compared with July/August. Importantly the experimentation showed that new roots could be initiated at any time during the year. Rooting success and yields might be further improved by the use of other rockwool rooting substrates such as the Grodan Master or Phoenix products that potentially allow better control over the slab's moisture content compared with the Grodan Talent used in the current experimental work.

At present two major constraints exist for continued cropping of tomatoes; one is the inability to carry out a thorough end of season clean up for pest and disease control within the glasshouse and the other is the low level of solar radiation experienced during the winter period in the UK.

The project has, however, developed improved techniques for initiating new root systems on the stems of tomato plants during the cropping period, through the use of gel kits. Establishing new roots could provide a useful technique with which growers could bypass *Botrytis* lesions without the loss of the fruit-bearing stem, as yields from the re-rooted stem are comparable to a conventional layered plant within a single season of crop production.

Science Section

Introduction

There is currently a period from November to February when there are very few home grown tomatoes available and large quantities of fruit are imported into the UK from Spain and the Canary Islands. The reason for this gap in supply is that every year the old crop has to be removed and new plants propagated and grown on. It generally takes around 15 weeks from sowing and 11 weeks from introducing new plants into the greenhouse before the first fruits are harvested. Traditionally crops are pulled out at the end of October or early November. A small number of growers who do crop throughout the winter period do so by pulling out plants early in order to replant in August or September and in so doing lose some production during late summer. The replacement of the old root system with a new one, rooted from the existing stem allows the old haulm to be removed with a fruiting crop *in situ* and thus facilitate continuous cropping through this period and beyond. In addition a major problem faced by U.K. tomato growers during the late summer and autumn is that of plant losses due to *Botrytis*. Old leaf scars, truss die back and cracked stems are a common route of *Botrytis* infection. By removing old haulm before *Botrytis* problems occur it is likely that losses due to *Botrytis* will be reduced.

Under certain conditions, tomatoes produce adventitious roots along the stem, which are air pruned and hence do not develop. Homberg (1987) demonstrated that such adventitious roots could become new root systems by growing stems through buckets containing peat. He established up to four root systems per plant in this way. Work by PBG at Naaldwijk, in 1997, has shown that the cropping period of cucumber plants can be extended by establishing an additional root system, closer to the fruiting part of the plant. New roots were established by enclosing cucumber stems in moist rockwool.

In late 1997 and early 1998, MAFF funded experiments at Efford and Arreton Valley Nursery on the Isle of Wight in order that methods for propagating new roots from layered stems could be developed in rockwool (MAFF, 1998). Various techniques including, scraping the stem and the use of hormone rooting powder were tested but were not found to give a higher success rate than simply enclosing the stem in moist rockwool. In these studies, layered stems were secured between wetted rockwool cubes and provided with a dripper. Under poor but improving light conditions at the end of February new adventitious roots were established 3-4 weeks after contact was made with the moist rockwool. Restricting water supply to the old root system was found to accelerate new rooting. In previous work at Efford (MAFF, 2000; HORTLINK, 2001) new roots were established using the same technique as above except that stems were enclosed in rockwool at the end of July in high light conditions. Roots emerged from the rockwool cubes surrounding the stems within 10 days of their application. In this experiment additional rooting resulted in vastly reduced losses of plants to *Botrytis* at the end of the season.

The technique of enclosing the stem in moist rockwool to stimulate adventitious rooting has the potential limitation that it is prone to *Botrytis* infection before new roots develop. A potentially more robust approach is to use hydrated gels that enable 'new roots' to be established before putting them in contact with the irrigated rooting medium. By sealing the gel around the stem, the chances of *Botrytis* infection are likely to be much reduced and the transparent gel would allow easy monitoring of new root development. The timing of old root detachment may be critical in determining the success of a 'new root' technique. Therefore measuring the time taken for a hydraulic continuum to form between the new roots and the transpiring shoot, may allow us to predict the optimum time to detach the old root system with minimum perturbation to shoot and root water relations. By continuing a crop through the winter there are likely to be implications for subsequent crop performance. Winter cropping is likely to reduce yields later in the season. Such effects need to be identified and evaluated in order that a full cost-benefit analysis is undertaken.

Materials and methods

Plant material for year 1 conventional and new root crop, nutrition and plot size

Tomato plants cv Espero were sown on 14 December 1999 by a commercial propagator and blocked into small rockwool cubes (Grodan DM65, 100 X 100 X 66 mm, Grodan, Denmark). Slab contact was made on 1 February 2000, to 1200 X 150 x 75 mm Grodan Talent slabs (Grodan, Denmark). Each experimental plot comprised 13 Talent rockwool slabs (29 m^2), each slab supporting the growth of four plants.

All plants received solutions containing the following levels of nutrients (mM): K 10, NO_3-N 11, Mg 3, P 1; and (µM) NH_4-N 250, Fe 36, Mn 9, B 37, Zn 15, Cu 2 and Mo 1. Solution pH was maintained at between 5 and 6 by adjustment with nitric acid and EC was 2.8 mS. Routine measurements of applied and drain EC was undertaken and samples analysed for major and minor nutrients. In addition within slab measurements of EC were made using a portable hand held EC-1 Sigma Probe (Delta-T Devices, Cambridge, UK). During the winter/spring period the glasshouse atmosphere was enriched to target concentrations of 1000 $\mu mol\ mol^{-1}$ CO_2. During the summer period CO_2 concentration was maintained at 500 $\mu mol\ mol^{-1}$ to accommodate increased venting in the summer months.

Botrytis was controlled using a combination of re-rooting affected stems and via fungicide applications. One application of Scala was made on 6 October 2000. Further chemical applications to the crop are detailed in Appendix 1.

Initiating and establishing a new root system

Supaplants Ltd (Sheffield University, Western Bank, Sheffield, S10 2TN), provided the gel used to initiate new roots from the stems of the growing plants. The gel consisted of special formulations of laponite with rooting hormones and nutrients and was coded '55'. The apparatus constructed to initiate rooting from tomato stems consisted of 10cm lengths of clear, flexible plastic tubing slit lengthways with a 5mm diameter hole at 90° to the slit. The cylinders were positioned around the stem and secured using 5cm wide sticky tape at either end. 70ml of gel was injected through the hole and in order to exclude light, a 10cm wide strip of black and white polythene sheet was wrapped around the cylinder with the black side innermost and secured with a piece of sticky tape. The root initiation vessels were located on stems just above the slab onto which they would make contact (see Plates 1 and 2). There were 6 drippers to each slab and therefore 3 drippers per cube. New roots were generated at two time-points towards the end of July (time 1) and the end of August (time 2; Table 1), with the control being a conventional crop. However between November 2000 and March 2001, stems bearing new roots were checked regularly for signs of rotting and a new root system from healthy stem created if necessary. At the end of March (27-28 March) it was decided for uniformity that all stems of new root plants that had not already been treated were regelled and a new root system initiated.

Once the second set of new roots had established then for the majority of plants the stems were cut at the stem base of the second root system. However at this stage the new roots technique was further refined to avoid the problems of stem rotting. Previously once the gel kit had been removed and the rooted stem had made contact with the rockwool slab it was secured and covered with plastic sheeting. If left, it appeared that the high humidity conditions under the secured sheeting that initially promoted the rooting process actually caused rotting of the stem. To avoid this as soon as new roots had rooted into the slab the secured plastic sheeting was removed and the stem exposed which markedly reduced stem rotting for re-rooted plants.

Crop husbandry for establishing new roots

The conventional and new root crops were identical at the start of the experiment with a population density of 1.79 plants m^{-2}. This was increased, by taking a shoot on every plant, to 3.59 m^{-2}. The crops differed in their treatment when new roots were established.

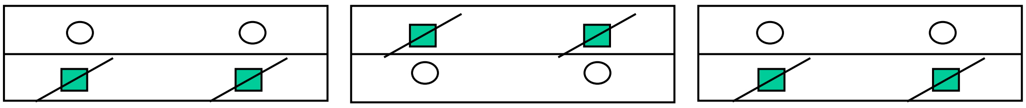


Diagram 1. The alternating new root slab (□) and old root slab (□) arrangement.

There were pairs of slabs parallel to each other, one providing the substrate for original roots (□) and the other for year 2 new root plant growth (□). The position of the 'old' and 'new' slabs alternates (Diagram 1). Each slab supported four plants (before sideshoots), propagated in two plant cubes, and each slab was irrigated from six drippers. New roots established on the stems would make contact with rockwool slabs in the positions indicated by the circles. At this stage two of the 6 drippers were moved from the old slabs to the new slabs (Table 1). The remaining drippers were moved across in stages according to new root establishment and sap flow data (see below). The old root systems were detached from these plants once new roots were sufficiently established. Typically 3-4 days later the old haulm was severed and removed from the glasshouse. In week 39 of 2000 (w/c 25 September) all heads in the conventional crop and 50% of heads in new roots crops were stopped. From week 37 (w/c 11 September) truss pruning began, restricting flowering trusses to 6 flowers/fruits. From week 40 (2 October) flowering trusses were restricted to 4 flowers/fruits each. The year 1 conventional crop was pulled out in week 46 making way for new plants that arrived in week 47.

Conventional year 2 crop

The new conventional crop cv Espero was sown on 30 October 2000 and placed in their final positions on 20 November 2000. The initial population density was 1.79 plants m^{-2}, matching that of the overwintered new roots crop. Side shoots were routinely taken to produce a summer population of 3.59 m^{-2} in both crops.

Table 1. Timetable for new root experimental treatments in 2000.

Week	New roots time 1	New roots time 2
2000		
31	Gels applied	
32		
33		
34	Slab contact/Switch 2 drippers	
35		Gel applied
36	Switch over 3rd dripper	
37	Switch over 4th dripper	Slab contact/Switch 2 drippers
38	Switch over 5th and 6th drippers	
39	Cut old stem	Switch 3rd dripper
40	Remove old stem	Switch 4th dripper
41		Switch 5th dripper
42		Switch 6th dripper/Cut old stem
43		Remove old stem

Assessment of fruit quality and yield

Fruit quality assessment framework

A random sample of twenty, size D (47-57 mm in diameter) fruits picked at colour stage 4/5 was drawn from the complete harvest of each plot once a month throughout the trial. The twenty fruits from each plot were then assessed individually for a range of fruit quality defects using a five point scoring system for each defect separately.

The five scores were 1A, 1B, 1C, II and Waste where 1A indicated no defect, 1B and 1C indicated slight and moderate defect, respectively, within Class I. Score II indicated sufficient defect to downgrade to Class II and Waste indicated sufficient defect to downgrade to waste (Appendix 2). For analysis, the defect measurements on the individual fruit in a sample were pooled using a weighted combination of the defect scores with weights chosen to reflect the severity of the defect. In this report, 1A fruit is given a weight of zero, 1B fruit is given a weight of one, 1C fruit is given a weight of two, Class II fruit is given a weight of three and Waste fruit is given a weight of four.

The overall weighted score was then scaled to cover the range 0 to 100. Thus a single 1A fruit would have a weighted score of zero, 1B a weighted score of 25, 1C a weighted score of 50, a Class II fruit a weighted score of 75 and a waste fruit a weighted score of 100. The combined weighted score of the twenty fruits in a sample therefore gave an average weighted defect score in the range 0 to 100 (**Eq. 1**).

Eq. 1 Weighted score =(1B+1C*2+II*3+waste*4)*100/N (where N=80 assuming twenty-fruit samples)

Tissue sampling for visual defects, firmness, mineral, sugar and acid content

Twenty fruits selected randomly from the total yield for each subplot were used for visual assessments of fruit quality (Appendix 2). These assessments were carried out once a month during the experimental period and yield and size grade-out was recorded on up to three occasions within each week (Monday, Wednesday and Friday).

Load (N) which gives an estimate of skin strength and *firmness* (N mm^{-1}), which is related primarily to the *firmness* of the pericarp were measured on twenty fruit using a materials testing system (Model LRX, Lloyd Instruments, Hants, UK). This consisted of a 5 mm diameter round-ended probe travelling at a constant velocity (0.17 mm s^{-1}) into whole tomato fruit. The twenty fruits that had been sampled for texture analysis were immediately frozen (-20°C). Subsequently soluble solids content (% Brix) and pH were determined on filtered juice extracted from thawed and pulped fruits.

Non-destructive plant measurements

The presence or absence of new roots in gel tubes was recorded weekly after gel application and plant survival was recorded regularly by counting the number of surviving heads.

Sapflow

Sapflow in intact plants was measured using a heat balance method which is described in detail elsewhere (Steinberg *et al.,* 1989). The installation and use of the gauges followed the recommendations of the manufacturer (Dynamax, Texas, USA). The outputs from the gauges were monitored every 15 s, and stored as 30 min means (Campbell CR10X datalogger and AM416 relay multiplexer; Campbell Scientific, Shepshed, UK), for subsequent computation of sapflow rates. Single 13 mm gauges (SGA 13-WS) were placed at three locations on a plant stem following new root slab contact i) at the base of plants thus representing flow from the original root system ii) on the ‘head’ side of new roots established on shoot one and ii) on the ‘head' side of new roots established on shoot 2.

Experimental design and statistical analysis

The design of the experiment was strongly constrained by the need to provide appropriate guarding for each experimental plot. During the winter period, the conventional plants were removed and over-wintered guard plants were needed to provide guards for the over-wintered experimental plants. In addition, the conventional plants needed separate re-planted guards in the spring of the second year. For these reasons, and to maximise the efficiency of the design, a systematic experimental layout (Appendix 3) with three sets of conventionally cropped and guarded plants, one set on the north, one set on the south and one set in the centre of the experimental area was used. The experimental plants with appropriate guards were disposed in two blocks between the three sets of conventional plants. One block contained two replicates of July rooted, another a replicate of August rooted plants and the remaining block containing two replicates of August rooted and one replicate of July rooted plants. Previous experience has shown that there can be north-south trend effects in this house therefore the design was chosen to be as robust as possible against north-south trend effects.

The data was analysed by a conventional analysis of variance model with a linear covariate trend to accommodate the effects of any north-south trend effect over the experimental area. Overall, there were three replicates of the three treatments and after eliminating the covariate trend effect, five residual degrees of freedom remained for error. Therefore all significance tests and estimates of standard errors and error variances are based on five error degrees of freedom.

Results

The speed of new root development

Roots developed in 84% of gel tubes applied at the end of July (time 1) after 3 weeks and in 91% of gel tubes applied at the end of August after 2 weeks (Figure 1). A new adventitious root system and gel kits are shown in Plates 1 and 2. It had been expected that root initiation might have been more prolific in July in response to higher light levels and water demand. The light sums for the two weeks following gel application were 229 and 174 MJ m^{-2} respectively for the end of July and end of August applications. The reasons why new roots developed faster at the end of August are not clear.

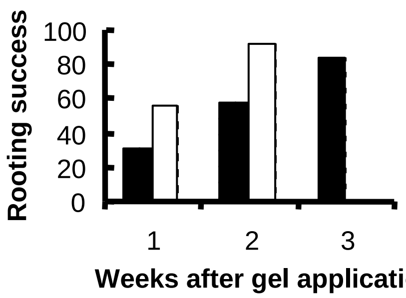


Figure 1. The effect of the timing of gel application on rooting success for new root (NR) time 1 in July (□) and 2 in August (□). Rooting success was measured as the percentage of 'gel kits' in which roots were present.

Sap flow

There were 2 stems on every plant and a new root system was developed on each stem. The combined flow from the 2 stems next to the new roots was higher than that from the base of the old stem as soon as slab contact had been made on 21 August Day 234 (Figure 2). Routine observations showed that the flow through the old stem slowly declined with time, and as drippers were relocated to new slabs containing the new root systems (data not shown).

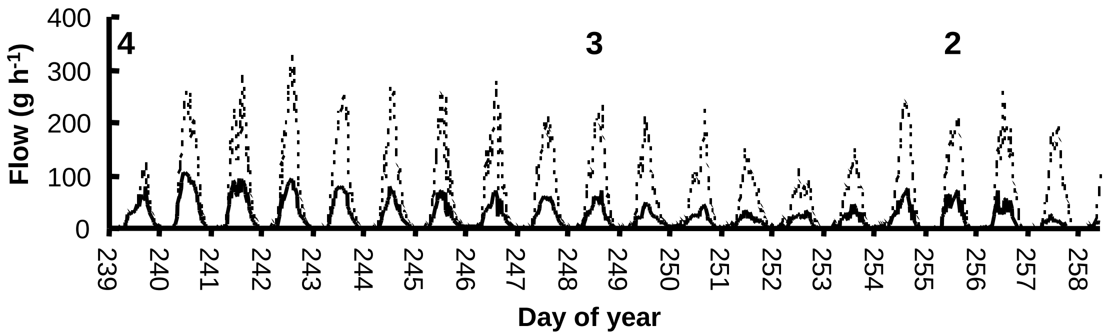


Figure 2. The effect of new roots (broken line) on water uptake compared with the control plants (solid line) from day 239-258. New roots were initiated on day 210. 4,

3 and 2 within the graph plot area indicates the number of drippers remaining in the old slab.

Plate 1. A new adventitious root system initiated in the 'gel kits' from sections of layered stem.

Plate 2. The location of gel kits along the stems of layered plants.

Slab EC changes as new roots replace the function of old roots

Slab EC changes following slab contact for new roots time 2 at Day 279 showed that new slab EC was beginning to increase, 24 days after slab contact. This is consistent with the time taken in new roots time 1. However the EC ranged from 2.5-3.5 and was below the level that would decrease yield in Espero (Mulholland *et al.,* 2002).

Effect of New Roots Treatments on Plant Losses

It was an aim of this experiment to determine the effect of the new root treatments on plant losses due to *Botrytis*. However *Botrytis* was not a problem during the first conventional cropping season. Figure 3 shows how plant numbers, represented in terms of plant density, changed during August, September and October.

Stopped heads for the control plants ceased to be counted from week 42. However in the new root treatments plant losses were evident in week 40 following the cutting of the old stems particularly at time 1 (Figure 3). Head numbers were reduced by 8%. These plants are presumed not to have developed sufficient new root systems and were still reliant on the old root system for water uptake. There were fewer plant losses (6%) in the new root time 2 treatment. Nevertheless by the end of the experiment there were fewer plants per unit area for the new root times 1 and 2 treatments 1.6±0.03 and 1.5±0.02 plants m^{-2} respectively compared with 1.8±0.02 plants m^{-2} in the control. Whilst plants were regelled as part of the management of the new

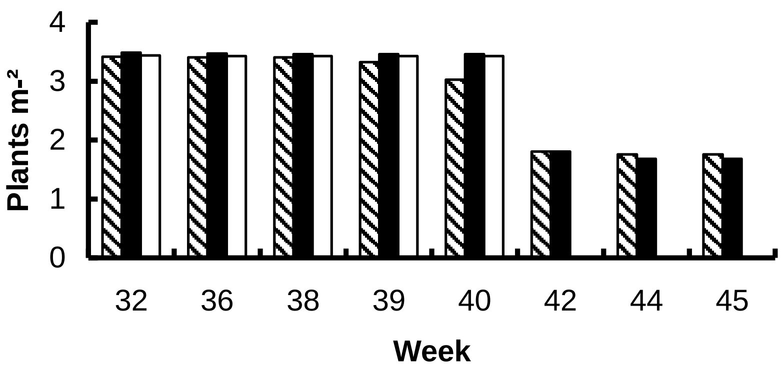


Figure 3. The effect of new roots on plant density in 2000 where the shaded, solid and no fill bar areas represent the new roots times 1, 2 and control respectively.

roots crop, to maintain head counts more than one side shoot was taken on selected plants throughout the experimental period. This may not have offset the reductions in yield (see Figure 4) through the lower plant numbers observed in the new roots treatment as the additional shoots developed on a single plant would not have replaced the vigour and yield potential of a separate plant with an optimum shoot number.

Effects of new root treatments on yield and grade-out

Yields from the new root treatments were comparable with those from the conventional crop up until October (Figure 4a, b). In October the conventional crop yielded higher (P<0.001) by 14.7%. This difference in yield may reflect in part the plant losses that occurred when the old stems were cut in new roots time 1 treatment. In addition the conventional crop plants were stopped on 25 September, that may have allowed more assimilates to accumulate in the remaining fruits. In contrast, in the new roots treatments, where 50% of plants remained unstopped, assimilates were shared between fruits set before 25 September and those set after that date.

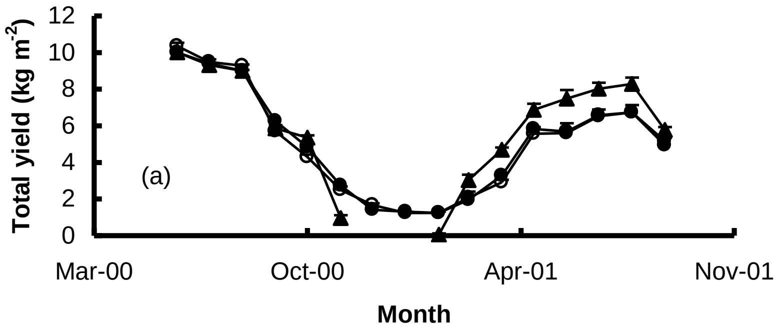
There were significant differences in yield that related to the timing of new root establishment. August yields were 3% higher (P<0.01) in new roots time 1 compared with time 2 (or the conventional crop), perhaps as a result of new roots allowing enhanced water uptake. However, this pattern was reversed in October following the cutting of old stems in the new roots time 1 treatment (Figure 4a, b). The new roots were higher yielding compared with the conventional crop in November (P<0.001). This was due to the final pick in the conventional crop being carried out on 13 November to allow plants to be removed in readiness for new plants arriving on 20 November. Whilst the new root treatments continued to produce fruit at a low level during the winter months, in March 2001 the conventional crop began to out-yield the new root treatments (P<0.05; Figure 4a,b). This continued until the last pick in September 2001. As a result of the reduced yield in the second half of the experiment, total yield for the entire experiment was reduced in the new root treatments compared with the control (P=0.075; Table 2). The lower yields also occurred with a constant reduction in plant numbers and a loss in % Class I fruit and an increase in waste particularly in the second half of the season (Figure 5a, b). The loss in % Class I fruit appeared to coincide with an increase in fruits exhibiting the physiological ripening disorder blossom-end rot (Figure 5c; Table 2).

Fruit size distribution exhibited seasonal patterns where fruit size Grade D fruits increased from early to late season whereas the larger Grade C fruits decreased (Figure 6a,b,c). There were some perturbations in the conventional crop during the first picks of 2001, where there was a greater proportion of larger fruits compared with the new roots treatment (P<0.01; Figure 6a, b, c). The stopping of heads in the conventional crop on 25 September suggested that there was a shift in fruit size towards larger fruits soon after. For example the proportion of size Grade C fruits increased at the expense of smaller fruits Grade E particularly in October and November 2000 compared with the new root treatments (P<0.05; Figure 6a,c).

Table 2. The effect of new roots and the timing of their application on a range of yield and fruit size grade-out variates over the duration of the experiment, 2000-2001.

Variate	Control	NR Jul	NR Aug	NR mean	Main treatment effects P value NR	Time	SED[1]	SED[2]
Total yield (kg m^{-2})	84.8	80.3	81.2	80.8	0.075	0.691	1.79	2.09
Total marketable yield (kg m^{-2})	83.8	79.1	80.2	79.7	0.071	0.628	1.81	2.11
% Class I fruit	97.7	97.1	97.3	97.2	<0.01	0.085	0.08	0.09
% Grade C	48.8	48.7	49.7	49.2	0.449	0.435	0.89	1.04
% Grade D	47.5	46.2	45.4	45.8	0.062	0.354	0.71	0.89
% Grade E	2.5	2.6	2.2	2.4	0.603	0.110	0.21	0.24
% Waste	1.1	1.5	1.2	1.4	0.154	0.145	0.14	0.16
BER (kg m^{-2})	2.0	13.3	10.6	12.0	<0.05	0.546	3.45	4.03

SED[1] represents standard error of the difference and is used for comparing new roots and the control and SED[2] for comparing means within new root treatments with 5 degrees of freedom.



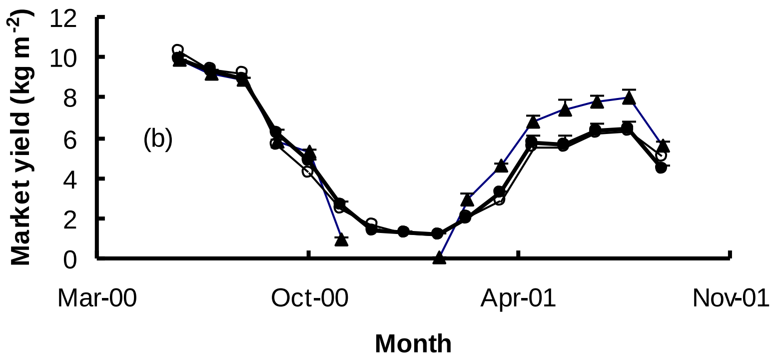


Figure 4. The effect on a) total yield and b) total marketable yield of (□) control and (O, □) new root (NR) initiated in July and August 2000 respectively. Vertical bars are standard errors of the difference (SED) with 5 degrees of freedom (d.f.).

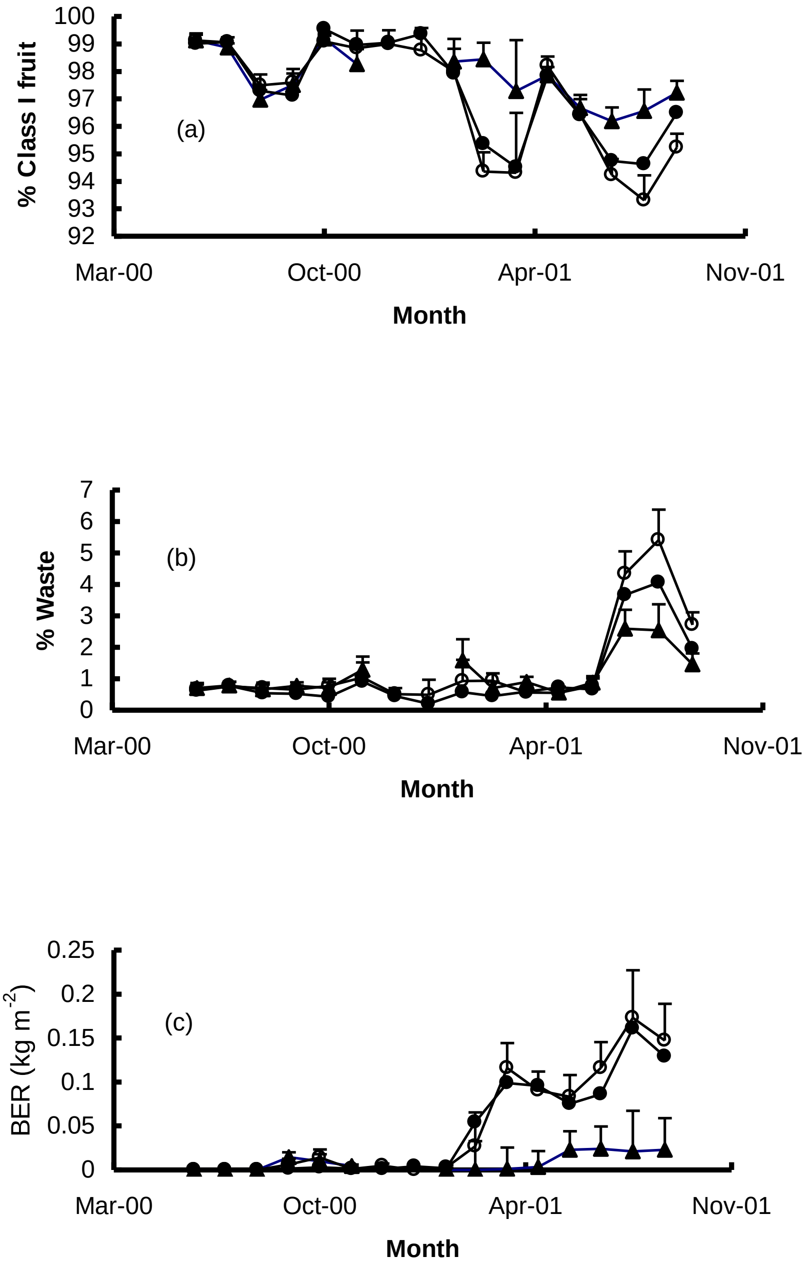


Figure 5. The effect on a) percentage Class I fruit, b) percentage waste and c) blossom-end rot (BER) for (□) control and (O, □) new root (NR) treatments initiated in July and August 2000 respectively. Vertical bars are SED with 5 d.f.

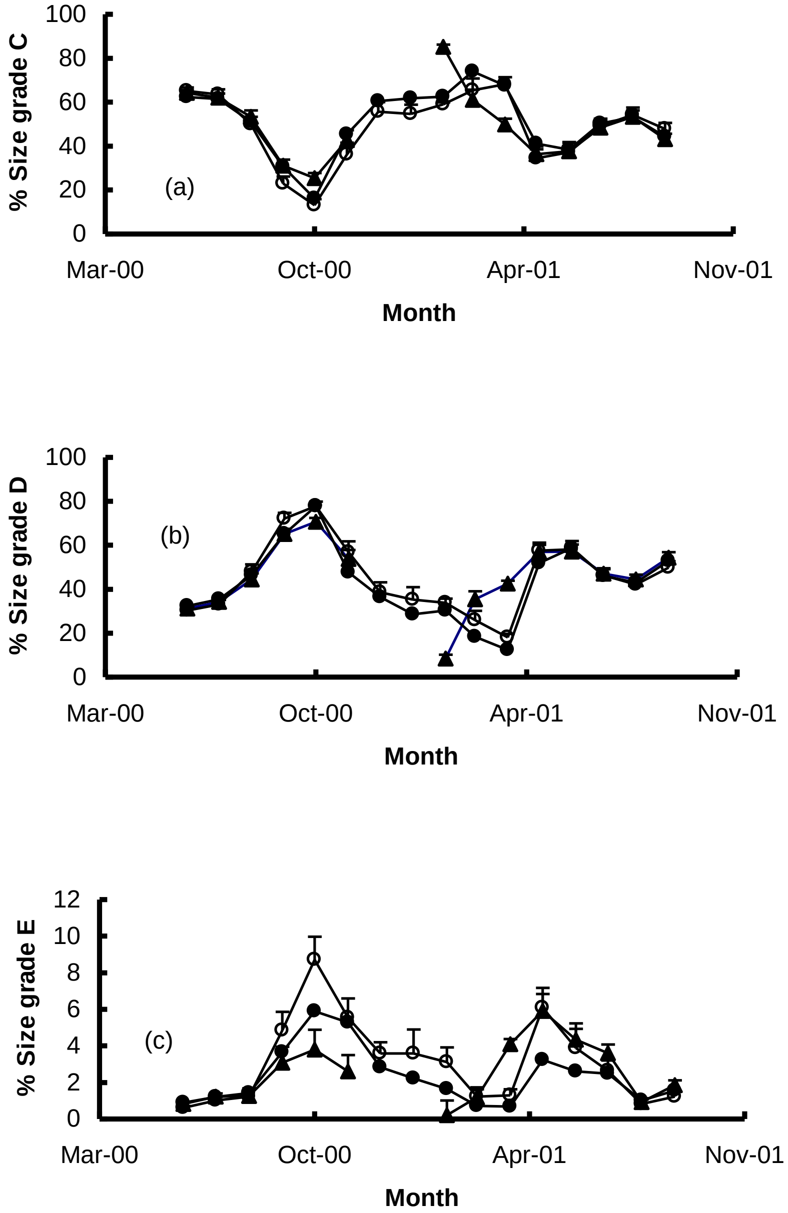
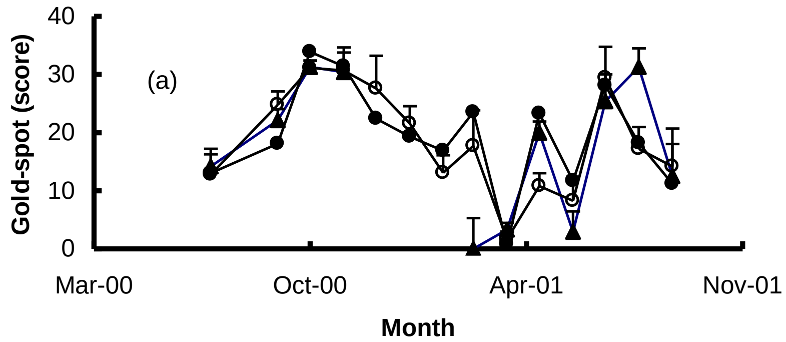


Figure 6. The effect on fruit size grade a) C (57-67 mm diameter), b) D (47-57 mm) and c) E (40-47 mm) of (□) control and (O, □) new root (NR) treatments initiated in July and August 2000 respectively. Vertical bars are SED with 5 d.f.

Fruit visual defects, texture and juice composition

There was little effect of the new root treatments on gold-spot (Figure 7a), but there were some increases in the incidences of uneven ripening particularly in the mid to late summer months June to September (P<0.05; Figure 7b). There was no effect of new roots on firmness and load (Figure 8a, b) but the incidence of uneven ripening fruit appeared to broadly correlate with reduced fruit juice acidity between April and August 2001 (P<0.05; Figure 9a). Conversely however between March and July fruit juice Brix concentrations were markedly higher in the new roots treatment compared with the control (Figure 9b).



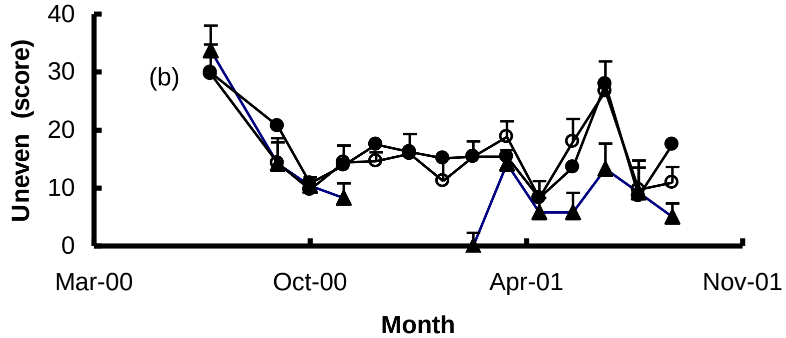


Figure 7. The effect on a) gold-spot and b) uneven ripening for (□) control and (O, □) new root (NR) treatments initiated in July and August 2000 respectively. Vertical bars are SED with 5 d.f.

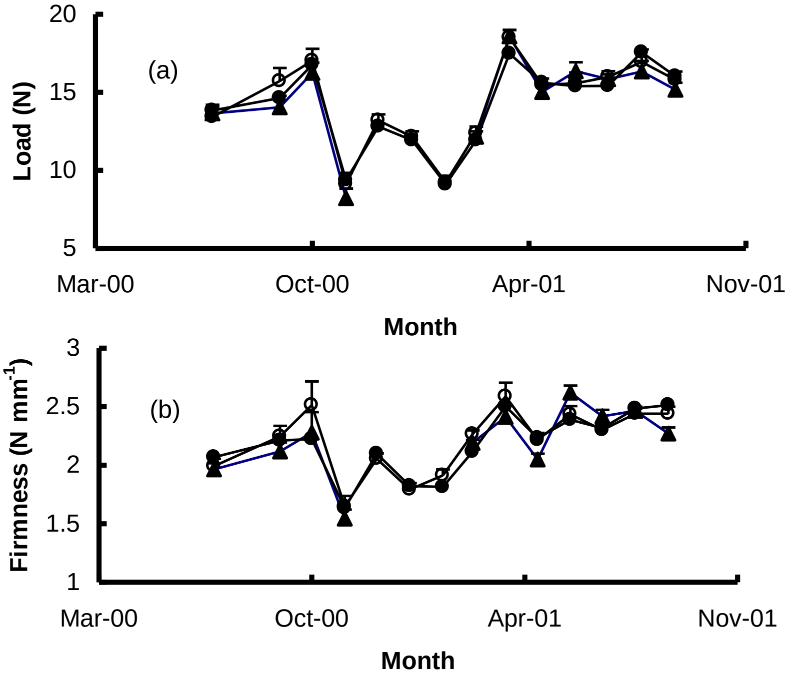


Figure 8. The effect on fruit a) load and b) firmness for (□) control and (O, □) new root (NR) treatments initiated in July and August 2000 respectively. Vertical bars are SED with 5 d.f.

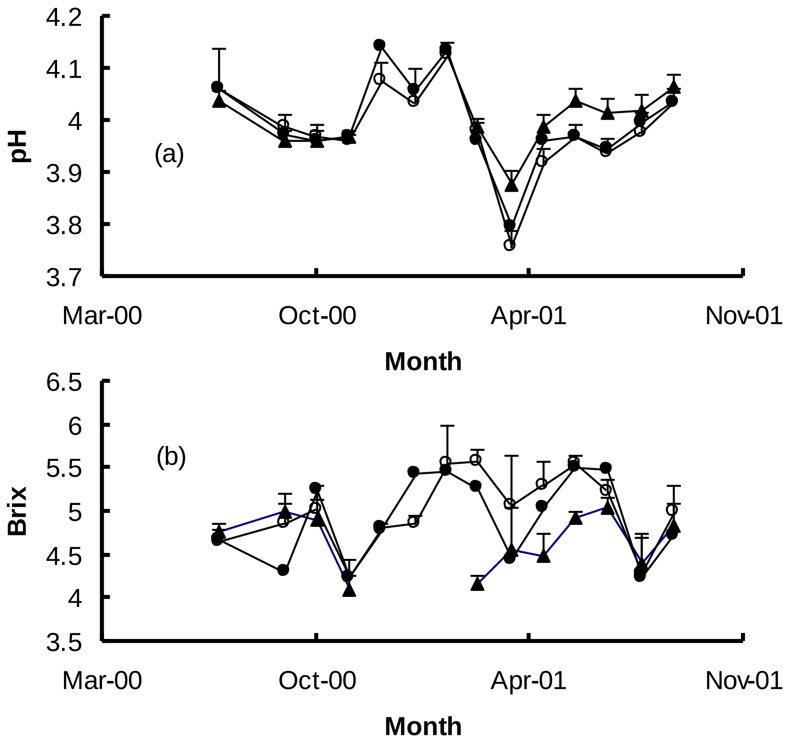


Figure 9. The effect on fruit juice a) pH and b) Brix for (□) control and (O, □) new root (NR) treatments initiated in July and August 2000 respectively. Vertical bars are SED with 5 d.f.

New roots cost benefit analysis

To assess the potential profitability of using new roots for continual cropping a cost benefit analysis was carried out. The overall difference in value for the new roots crop compared with the control was minus £2.55 per m^2 which represents a significant monetary loss (Table 3). In addition, the cost of applying the new roots has to accounted for and was £4.44 per m^2 (Table 4). Over the entire experiment the new root technique represented a total loss in profitability of £6.99 per m^2 compared with the conventional crop.

Table 3. Yield differences and cost for conventional and new root crops. The cost per kg has been calculated for the mean price of size Grade D fruit for each month.

	Yield			**Price**	
Month	Control kg per m^2	New roots kg per m^2	diff kg per m^2	£ per kg	diff £ per m^2
Jun 2000	9.94	10.12	0.17	0.53	0.09
Jul	9.24	9.37	0.13	0.58	0.08
Aug	8.94	9.09	0.15	0.61	0.09
Sep	5.82	5.95	0.14	0.63	0.09
Oct	5.33	4.54	-0.79	0.74	-0.58
Nov	0.95	2.59	1.64	0.70	1.15
Dec 2000	0.00	1.53	1.53	0.75	1.15
Jan 2001	0.00	1.27	1.27	0.60	0.76
Feb	0.06	1.23	1.17	0.76	0.88
Mar	3.02	2.00	-1.02	0.91	-0.93
Apr	4.65	3.08	-1.58	0.77	-1.21
May	6.84	5.66	-1.18	0.66	-0.78
Jun	7.42	5.60	-1.82	0.57	-1.04
Jul	7.82	6.29	-1.53	0.59	-0.90
Aug	8.07	6.42	-1.66	0.58	-0.95
Sep 2001	5.70	4.76	-0.94	0.47	-0.44
Total	83.78	79.48	-4.30		-2.55

All labour is costed at £7.75 per hour and general crop work includes picking, training, de-leafing, spraying, pulling out and stringing new plants. There was minimal additional cost for the new root treatments for an extra week of CO_2 water and nutrients that has not been allowed for.

Table 4. The cost of additional installation and crop management operations for the new root treatments compared with the conventional control cropping system.

		Treatment costs		
Operation	**Item**	Control £ per m^2	New roots 1 £ per m^2	New roots 2 £ per m^2
Materials	Gel kits 2000		1.69	1.69
	Gel kits 2001		0.85	0.85
	Plants	0.87		
	Gas (1 week)		0.19	0.19
Labour	Installing kits 2000		0.86	0.86
	Installing kits 2001		0.43	0.43
	Slab contact 2000		0.86	0.86
	Slab contact 2001		0.43	0.43
	Total	0.87	5.31	5.31

Discussion

The conclusions from the first year report suggested that the additional yield accrued during the winter period in the new root treatments whilst the conventional crop was replaced in late 2000 would offset the cost of installing the new root kits (Table 4). In addition it was suggested that the new root treatments would reduce plant losses to *Botrytis* compared with the conventional crop in the latter part of the year 1 season. However, *Botrytis* appeared not to be a problem in the conventional crop in 2000 or 2001 and therefore beneficial effects of reduced *Botrytis* infection in new root cropping systems observed in previous MAFF funded work (MAFF, 2000) were not repeated. This suggests that the reasons for plant losses to *Botrytis* are complex and may be closely related to specific environmental factors, the investigation of which were beyond the remit of the current project. Nevertheless growers could use the new root method to bypass *Botrytis* lesions and thus maintain plant density and therefore crop yields. Importantly the experimentation showed that a new root system could be initiated at any time during the year and that yields produced from the surviving stem were comparable with a single layered stem within a single cropping season.

Despite continued cropping, yield returns were low for the new root treatments compared with the replanted control during the second year, 2001. Much of the yield loss appeared to be due to the downgrading of fruit because of poor quality. Plants were re-rooted in March 2001 to potentially offset reductions in fruit quality. However this additional rooting operation did little to reverse the loss in quality and added to the cost of the new root treatment. Indeed, in the second half of the experiment between March to September 2001 blossom-end rot became a particular problem along with reduced acidity and uneven ripening in the new root crop. Whilst water uptake was improved during the early stages of new root establishment (Figure 2) it has been demonstrated that Ca accumulation within the fruit is not significantly affected but that Ca uptake is stimulated proportionately more than is K (MAFF, 2000). As the new root system and shoot aged it could be that the plant was less effective in capturing and transporting Ca to the fruits. However, all new root plants from 2000 were re-rooted in March 2001 and therefore even an additional new root system could not reverse the trend of increasing incidence of blossom-end rot (BER) as the crop aged. As fruit yield increased from March to August it could be that supply from the roots could not keep pace with demand for Ca from the shoot and fruit and therefore localised Ca deficit occurred in the fruit, which lead to, increased incidences of BER (Ho, 1998). The data suggests that the demand for Ca and the incidence of BER is controlled by factors in the shoot rather than in the roots. Reduced demand for Ca and K in the ageing shoot has also been observed in the HORTLINK summer fruit quality work (HORTLINK, 2001).

Uneven ripening was also increased in 2001 particularly between June to September. Observations by staff managing the experiment at HRI Efford suggested that the canopy was thinner i.e. individual leaf size was reduced in the new root crop compared with the control (Plate 3). This could have lead to increased heating of individual fruits because of reduced shading from leaves and direct exposure of the fruit surface to solar radiation. This could be significant, as it has been discovered that high temperature was the key driving variable for increasing the incidence of uneven ripening during the summer months (HORTLINK, 2001). Low-acidity observed in fruit sampled from the new root treatments may have been in part influenced by reduced malic acid concentrations within the fruit juice that are known to be adversely affected by high temperature (HORTLINK, 2001). However sugar levels appeared to be stimulated in the new root fruit. Reduced fruit yield may have been linked to the observed reduced leaf area and the growth habit of the plants during the second half of the experiment in 2001 suggests that they were in some way stressed (Mulholland *et al.,* 2002). Reductions in shoot water accumulation usually result in increased sugar accumulation within the fruit and also a decrease in fruit size (Mulholland *et al.,* 2002). However during this period fruit size distribution did not appear to be adversely affected in the new root treatment (Figure 6) and therefore the reduction in yield may have been due to a decrease in the number of fruit produced (data not recorded). The increase in sugar accumulation within the fruit may also have come about due to a reduction in the leaf / fruit ratio of the plant i.e. a greater proportion of photo-assimilates being partitioned to the fruits in the new root treatment compared with the control (Ho, 1998).

Conventional **New roots**

a) **b)**

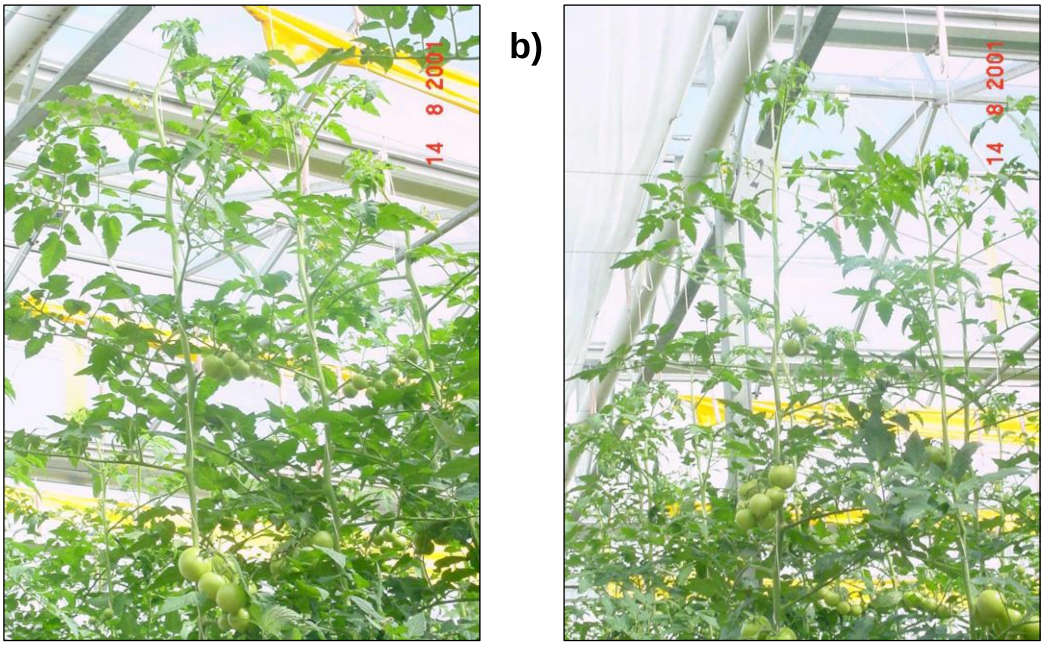


Plate 3. Observations on 14 August 2001 demonstrating the difference in canopy development for the a) conventional and b) new root crop. Note the smaller leaf areas towards the top of the canopy in the new root treatment.

The cost benefit analysis showed that significant losses in profitability were incurred by using the continued cropping new root system of £6.99 m^{-2}. However yields may be improved in the new roots treatment by the use of supplementary lighting, to theoretically improve carbon assimilation over the winter period. The conventional cropping system allows a break in production and the 'clean up' of the glasshouse. Considerable problems with whitefly were encountered in the new root crop during the early part of 2001. This may have had some impact on the poor growth of new root plants during 2001. In addition both the conventional and new root crop were grown using the same irrigation line. The amount and frequency of irrigation was geared towards the needs of the conventional crop and therefore inadvertently the new root crop may have suffered due to different irrigation requirements during the course of the experiment. Rooting success and yields may have been further improved by the use of other rockwool rooting substrates such as the Grodan Master or Phoenix products that potentially allow better control over the slab's moisture content compared with the Grodan Talent used in the current experimental work. Meeting more closely the water and nutrient needs of the new root crop could be an additional focus of future studies to effectively extend the cropping season under UK conditions.

Conclusions

- An improved technique for propagating roots from layered stems of tomato plants using gel kits has been developed. The gel can be sourced from Supaplants Ltd. (Sheffield University, Western Bank, Sheffield, S10 2TN).
- Application of the gel kits at the end of August resulted in improved rooting and plant survival following old root detachment compared with the application of gel kits at the end of July.
- Generating sufficient new roots for re-rooting into rockwool slabs took approximately 2 weeks. Following slab contact and the switching of drippers from old to new slabs it was another 5 weeks before the old root system could be detached.
- Initially yields were broadly comparable to the conventional crop in September and October but whilst continuous cropping produced fruit during the winter period of 2000 / 2001 total monthly yields were low, 2.59-1.23 kg per m^2, between November and February. However the replanted conventional crop had out yielded the new root crop by 1.02 kg per m^2 in March 2001. This trend continued until the end of the experiment in September 2001.
- Leaf area appeared to be reduced in the new root treatment compared with the conventional crop control during 2001.
- Fruit quality was adversely affected during the second year of growth in the new root crop between March and September 2001, with significantly higher incidences of blossom-end rot and uneven ripening fruit and thus the downgrading of significant quantities of fruit.
- The new roots continuous cropping system represented a total loss in profitability over two seasons of production of £6.99 per m^2

Technology transfer and further work

Presentations and demonstrations

- A presentation of the project was made to a joint meeting of the Tomato Working Party and the Hampshire Isle of Wight Tomato Study Group at Wellesbourne on 15 February 2000.
- The experiment was viewed and findings discussed with the Hampshire and Isle of Wight Tomato Study Group at a meeting held at Efford on 21 December 2000.

Suggestions for further R&D

- Further development of the stem rooting technique should focus on incorporating gels into purpose made rockwool sleeves that could more easily be applied to the stem and for slab contact.
- More work is required on optimising the timing of new root initiation from layered stems for continual cropping. It could be that re-rooting the crop in October / November would result in the best performance in the second year of cropping.
- Testing of other forms of rockwool substrates are required to explore whether better control over the slab's moisture content improves rooting success and yield returns for the new roots method.
- Innoculation experiments are needed to confirm that plants with visible *Botrytis* stem lesions can be saved by re-rooting the layered stem and thus can effectively bypass the lesion. The low level of *Botrytis* in this study has resulted in little data being collated in this area.
- Further economic evaluation of continually cropping tomatoes or winter cropping tomatoes should include investigations into the use of hanging gutters, inter-planting and the use of supplementary lighting.

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Appendix 1

Record of spray applications for 2000 and 2001

Date	Spray	Active ingredient	Target organism
28 Apr 2000	Torq	Fenbutatin Oxide	Red Spider Mite
7 Jul 2000	Thiovit	Sulphur	Powdery mildew
4 Aug 2000	Savona	Fatty acids	Whitefly
17 Aug 2000	Applaud	Buprofezin	Whitefly
1 Sep 2000	Savona	Fatty acids	Whitefly
7 Sep 2000	Dynamec	Abamectin	Red Spider Mite
8 Sep 2000	Thiovit	Sulphur	Powdery Mildew
6 Oct 2000	Scala	Pyrimethanil	Botrytis
16 Oct 2000	Savona	Fatty acids	Whitefly
30 Oct 2000	Applaud	Buprofezin	Whitefly
17 Nov 2000	Savona	Fatty acids	Whitefly
23 Nov 2000	Applaud	Buprofezin	Whitefly
30 Nov 2000	Mycotal	Verticillium lecanii	Whitefly
18 Dec 2000	Thiovit	Sulphur	P.Mildew
25 Jan 2001	Savona	Fatty Acids	Whitefly
29 Jan 2001	Eradicoat	Polymer and natural organic plant extract	Whitefly
5 Feb 2001	Applaud	Buprofezin	Whitefly
9 Feb 2001	Mycotal	Verticillium lecanii	Whitefly
21 Feb 2001	Savona	Fatty Acids	Whitefly
23 Feb 2001	Eradicoat	Polymer and natural organic plant extract	Whitefly
7 Mar 2001	Thiovit	Sulphur	P.Mildew
8 Mar 2001	Scala	Pyrimethanil	Botrytis
13 Mar 2001	Savona	Fatty Acids	Whitefly
19 Mar 2001	0.5% Calcium Chloride	Calcium Chloride	BER
20 Mar 2001	Eradicoat	Polymer and natural organic plant extract	RSM
21 Mar 2001	Savona	Fatty Acids	Whitefly
22 Mar 2001	Applaud	Buprofezin	Whitefly
26 Mar 2001	Mycotal	Verticillium lecanii	Whitefly
29 Mar 2001	Calcium chloride	Calcium Chloride	BER
3 Apr 2001	Savona	Fatty Acids	Whitefly
5 Apr 2001	Eradicoat	Polymer and natural organic plant extract	Whitefly
10 Apr 2001	Calcium chloride	Calcium Chloride	BER
12 Apr 2001	Eradicoat	Polymer and natural organic plant extract	Whitefly
30 Apr 2001	Eradicoat	Polymer and natural organic plant extract	Whitefly
9 May 2001	Eradicoat	Polymer and natural organic plant extract	Whitefly
15 May 2001	Eradicoat	Polymer and natural organic plant extract	Whitefly
16 May 2001	Thiovit	Sulphur	P.Mildew
23 May 2001	Eradicoat	Polymer and natural organic plant extract	Whitefly
7 Jun 2001	Calcium chloride	Calcium Chloride	BER
27 Jun 2001	Thiovit	Sulphur	P.Mildew
23 Jul 2001	Torq	Fenbutatin Oxide	RSM
17 Aug 2001	Thiovit	Sulphur	P.Mildew

Appendix 2

Defect recording system

The scoring system for defects is based on the EC common standards for quality of round tomatoes:

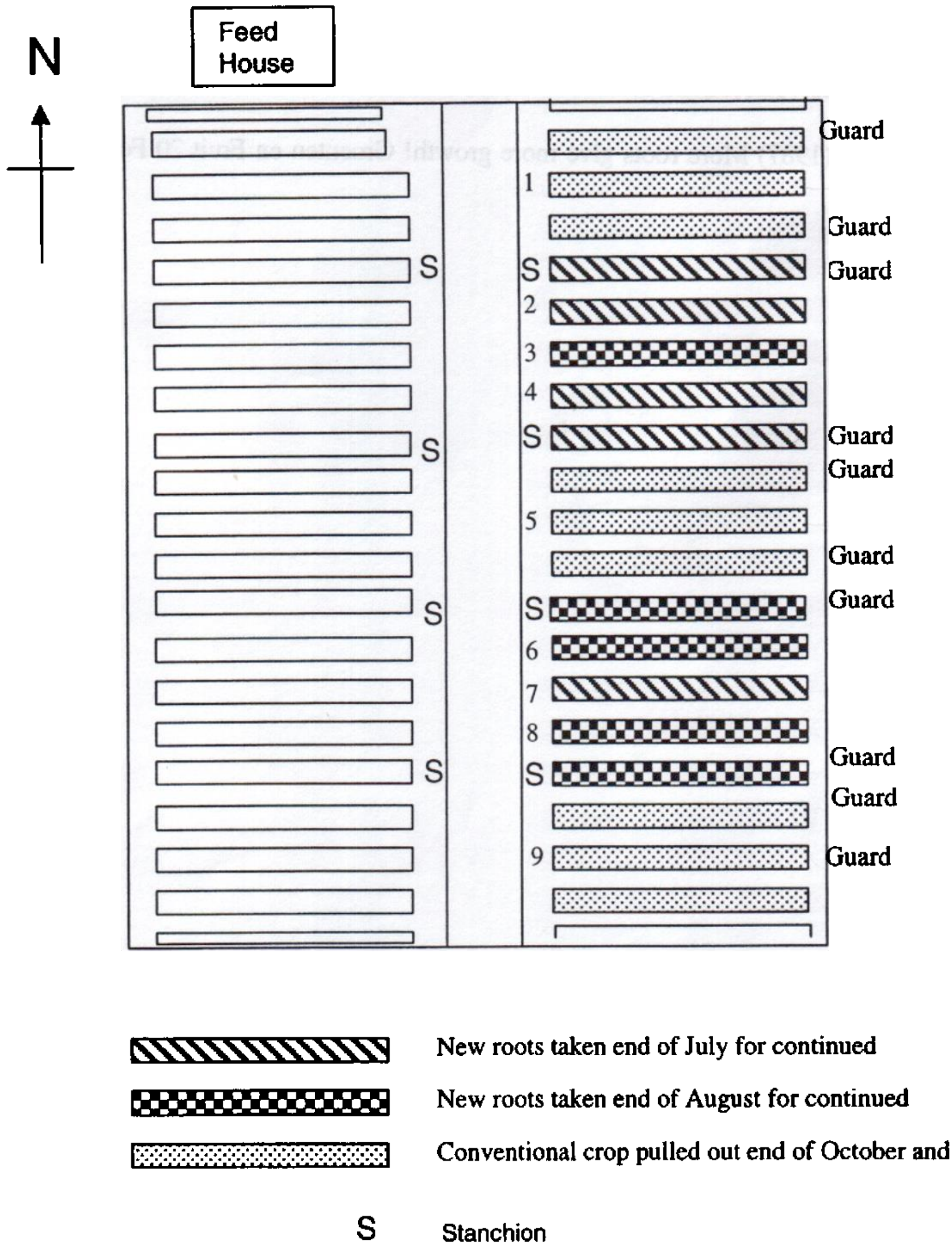
1A	Absent or virtually absent	Class I
1B	Present at a low levels	Class I
1C	Noticeable but still acceptable for	Class I
2	Present at acceptable level for	Class II
3	Unacceptable level	Waste

Acceptable levels of common defects

Defect	1B	1C	2	3
Blotchy Ripening	1-3 blotches < 5mm diam.	4-6 blotches any one 6 - 10mm	> 6 blotches or any one 11-30mm	Any one blotch 30mm diam.
Dark Patches (like bruises)	1-3 blotches < 5mm diam.	4-6 blotches any one 6 - 10mm	> 6 blotches or any one 11-30mm	Any one blotch > 30mm diam.
Uneven Ripening	1 ATB Col Stage difference	> 1 ATB Col Stage difference	-	-
Gooseberry Veining	<30% surface area	>30% surface area		
Softness	Moderately firm	Slightly soft	Soft (tender)	Very soft
Gold Spot	< 100 spots/cm² or < 10mm radius around calyx	> 100 spots/cm² and 11-20mm radius around calyx	> 100 spots/cm² and > 20mm radius around calyx	-
Gold Marbling (flecking)	1-20mm diam.	21-40mm diam.	>40mm diam.	-
Net Cracking (russetting)	wide net or < 1cm² close net	1 - 2 cm² close net	< 50% close net	> 50% close net
Concentric Cracking	Total length of all cracks < 5mm	Total length of all cracks 6 - 10 mm	Total length of all cracks 11 - 30mm	Total length of all cracks > 30mm
Blossom-End Rot	-	-	-	Any

To provide a general score to represent the level of a defect averaged across treatments the following weightings were used:
Score = ((0*1a)+(1*1b)+(2*1c)+(3*II)+(4*waste))*100/sample number

Appendix 3



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New roots taken end of August for continued
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