HORTICULTURE RESEARCH INTERNATIONAL

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HDC Contract PC/65a

REGULATION OF TOMATO FRUIT SIZE BY TAKING SIDE SHOOTS

Final Report

FINAL REPORT (March 1994)

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REGULATION OF TOMATO FRUIT SIZE BY TAKING SIDE SHOOTS

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REGULATION OF TOMATO FRUIT SIZE BY TAKING SIDE SHOOTS

Relevance to growers and practical application

Application

As many market outlets prefer tomato fruit in the D size grade, it is beneficial to produce a high proportion of fruit in this grade throughout the production season. Earlier work showed that planting at a lower density than normal and then taking side shoots beginning in week 9, reduced the initial cost of planting and produced fruit of more uniform size for much of the cropping season. The present work explored the effect of planting at a low density and then taking side shoots in different patterns and starting at different times. Taking side shoots in two batches, each one month apart had the same effect as taking them in four batches, each two weeks apart. Taking side shoots starting as early as either week 3 or week 5, considerably reduced the variation in mean fruit size from month to month, gave a high proportion of grade D fruit throughout the cropping season (especially in the first few weeks of picking), and produced yields of marketable fruit that, in summer, were as high as those produced by crops planted at high density.

Summary

The market prefers Class I fruit in the D size grade but it is difficult to obtain a high proportion of fruit in this grade throughout the period of cropping of a long-season tomato crop. The main reason for this is an imbalance between the amount of assimilate produced by the crop in response to the solar radiation incident upon it, and the number of fruit available to use the assimilate for growth.

Previous work (HDC PC65) demonstrated that in the early part of the year, when daily light integrals were small, there was an advantage in growing plants at low density for, plants grown at high density produced too many fruit, many of which were then too small (i.e. grade E). On the other hand, when daily light integrals increased, there was an advantage in growing plants at high density for, by then, plants grown at low density did not produce sufficient fruit and so these fruit were often too large (i.e. grade C).

The present work was undertaken, therefore, to see if it was possible to get a better match between assimilate production and fruit number, and so produce a higher proportion of fruit in the preferred size grade throughout the year. Assimilate production varies in relation to incident solar radiation while the proportion of assimilate distributed to fruits remains relatively constant. We, therefore, attempted to change the number of fruit available per m^2 of crop by planting at low density, and then taking side shoots, starting either in weeks 3, 5, 7, or 9. The crop was 'Liberto', sown on 5 November and grown in NFT at the equivalent of 8250 plants per acre (low density). The equivalent of 4126 heads per acre were added as

side shoots to bring the effective density up to the equivalent of 12 376 plants per acre (high density). The required number of side shoots was added either in two batches, each one month apart or in four batches, each two weeks apart.

The results showed that there were no significant differences between the two patterns of taking side shoots, but there were clear differences between the four times of starting to take side shoots. For most aspects of yield and fruit size, the monthly means of the side-shoot treatments frequently formed a linear series ranging from the week 3 treatment through to the week 9 treatment, which was always slower to acquire the attributes of plants grown at high density. When side shoots began to be taken as early as either week 3 or week 5, these two treatments produced changes in the number of fruit per m^2 per month that most closely matched the changes in incident solar radiation per m^2 per month. Consequently, mean fruit weight in these treatments was more uniform throughout the cropping season than in either the high density or the low density control treatments. These two side-shoot treatments also produced higher yields of marketable, Class I, and grade D fruit than the low density control, especially in the summer from weeks 21 to 32. Overall, 80% of the Class I fruit were of grade D from these two treatments and the beneficial effects of planting at a low density and then taking side shoots were particularly evident in the first four weeks of picking when more than 85% of the Class I fruit were of grade D.

Although the presence of a developing side shoot would be expected to compete for light and assimilates with the fruit-bearing main stem, there was no evidence that this had any detrimental effect on yield, even when the side shoots were taken as early as weeks 3 and 5. Competition, however, was probably the cause of the slight increase in the yield of grade E fruit and of the reduction in mean fruit weight that occurred in the first few weeks of picking from side-shoot treatments, before any fruit had been picked from the side shoot stems.

There are evident benefits to growers from planting at a low density and then beginning to take side shoots as early as either week 3 or week 5. The most obvious advantage is that fewer plants need to be purchased per unit cropped area. Other advantages are that mean fruit weight is more uniform throughout the cropping season; a high proportion of grade D fruit is maintained throughout the cropping season but especially in the first few weeks of picking when more than 85% of the Class I fruit may be of grade D, and high yields of marketable, Class I, and grade D fruit can be sustained in summer. The results also indicate that the required number of side shoots can be added either in two batches, each one month apart or in four batches, each two weeks apart.

EXPERIMENTAL SECTION

INTRODUCTION

When a long-season tomato crop is grown at one plant density throughout its life, experience shows that it is highly likely to produce either too many small fruit in the early part of the season, if planted at high density, or too many large fruit in summer, if planted at low density. The main reason for this behaviour is an imbalance between the amount of assimilate produced by the crop in response to the solar radiation incident upon it, and the number of fruit available to use the assimilate for growth. Consequently, to produce fruit of uniform size throughout the year, it is necessary to get a better match between the number of fruit per m^2 of crop and the quantity of solar radiation incident per m^2 of crop.

The market prefers Class I fruit in the D size grade, i.e. 47-57 mm in diameter; 50-90g fresh weight, and in earlier work (HDC Project PC65), we demonstrated that it was possible to produce a higher proportion of fruit in the preferred size grade in the early part of the season by means of removing distal fruit from early trusses, i.e. by truss thinning. Furthermore, by planting at a low density and then increasing the effective density by taking side shoots, it was even possible to produce a higher proportion of fruit in the preferred size grade all through the cropping year.

In the earlier work, one crop was planted at the equivalent of 8250 plants per acre (low density) and side shoots were added to raise the effective density to the equivalent of 12 376 heads per acre (high density). One half of the required number of side shoots was taken in week 9 and the other half in week 14. The presence of the developing side shoots had only a small and non-significant adverse effect on the yield of fruit produced by the main shoots. The first fruit were picked from side shoots about 10 weeks after the shoots were taken and about 13 weeks elapsed before there was either any significant increase in yield or change in the pattern of fruit size. In the above example, therefore, side shoots taken in week 9 significantly increased both yield and average fruit size from week 22 onwards. This was regarded as too late by some growers and so, in the present experiment, we examined the effect on yield and fruit size of starting to take side shoots as early as weeks 3, 5, and 7, as well as week 9. Also, in an attempt to get a closer match between increases both in solar radiation and in fruit number, the required number of side shoots was taken either in two batches, each one month apart, or in four batches, each two weeks apart. As before, control crops were grown at either the initial or the final density throughout.

THE EXPERIMENT

1. The crop

Seed of 'Liberto' was sown on 5 November 1992, transplanted into rockwool cubes and raised in a propagating house on solid benches equipped with a sub-irrigation system for nutrient circulation and with supplementary lighting. Young plants were transferred to the main glasshouse on 9 December 1992 and planted at the appropriate density in NFT gullies. An NFT system was used because of the difficulty of choosing an appropriate irrigation schedule for crops grown at different densities in rockwool. The crop was trained and layered, as necessary and side shoots were normally removed at the earliest opportunity. Nutrient levels were changed through the season, following conventional procedures. The electrical conductivity of the nutrient solution was gradually raised from an initial level of 3 mS cm^{-1} (at planting) to 12 mS cm^{-1} by 24 December, then lowered again to 5 mS cm^{-1} by 26 February, and then to approximately 3 mS cm^{-1}, from 7 June. Electrical conductivities above 3 mS cm^{-1} were achieved by adding NaCl to a basic solution composed of (mg l^{-1}):- N = 180, K = 360, P = 30, Ca = 200, Mg = 80, Fe = 15, Mn = 0.75, B = 0.4, Zn = 0.5, Cu = 0.3, and Mo = 0.05. The flow rate down the NFT gullies was 2.5 to 3.0 litres per minute. Pollination was by "electric bee" until bumble bees were introduced from 12 January.

2. The glasshouse and aerial environment

The experiment was conducted in two adjacent compartments (each 17.3m x 7.9m; 2.54m to the crop wire) of an east-west oriented, single-span, Frampton Ferguson glasshouse. Air temperature was controlled at appropriate ADAS 'Blueprint' settings; additional carbon dioxide (CO_2) was provided from pure CO_2 and the atmospheric concentration was controlled at a set value of 1000 vpm CO_2 until 7 April. The CO_2 concentration was then lowered and, from 16 April, was controlled at approximately 450 vpm, regardless of ventilation. To aid the production of uniform aerial environments within the two adjacent compartments, the communicating door between them was removed, as were some panes of glass from the intervening partition. This enabled air (and bees) to pass from one compartment to the other.

Each compartment contained 24 NFT gulleys (7.70m long) arranged in 12 pairs and placed so as to slope from N to S (1:100). Each pair was supplied with nutrient (minimum temperature *c.* 18°C) from a separate tank located in a duct at the south end of the compartment and the distance between pairs of double rows was 1.53m. Each pair of gulleys represented a treatment plot.

3. The layout

The experimental design treated each compartment as a block that contained all treatments. The taking of side shoots was started at four separate times (i.e. early = week 3; mid-early = week 5; mid-late = week 7; or late = week 9), and for each time of starting, either one half of the required number of side shoots was taken on each of two occasions, one month apart or one quarter of the required number of side shoots was taken on each of four occasions, two weeks apart (see Section 4). There were, therefore, eight side-shoot treatments, i.e. 4 times of taking x 2 patterns of taking side shoots. In addition, two control treatments were planted, one at the initial low density and one at the final high density. These treatments were laid out in a graded manner with the gradients reversed in the two compartments (Fig. 1). The outer double rows of each compartment were guards planted at either low or high density, as appropriate.

Fig. 1. The layout of the glasshouse compartments

Plot No. Treatment

24	Low density guard
23	Low density control
22	Week 9 (4 * 1) side shoots
21	Week 9 (2 * 2) side shoots
20	Week 7 (4 * 1) side shoots
19	Week 7 (2 * 2) side shoots
18	Week 5 (2 * 2) side shoots
17	Week 5 (4 * 1) side shoots
16	Week 3 (4 * 1) side shoots
15	Week 3 (2 * 2) side shoots
14	High density control
13	High density guard

12	High density guard
11	High density control
10	Week 3 (4 * 1) side shoots
9	Week 3 (2 * 2) side shoots
8	Week 5 (2 * 2) side shoots
7	Week 5 (4 * 1) side shoots
6	Week 7 (4 * 1) side shoots
5	Week 7 (2 * 2) side shoots
4	Week 9 (2 * 2) side shoots
3	Week 9 (4 * 1) side shoots
2	Low density control
1	Low density guard

4. The treatments

4.1 Control treatments

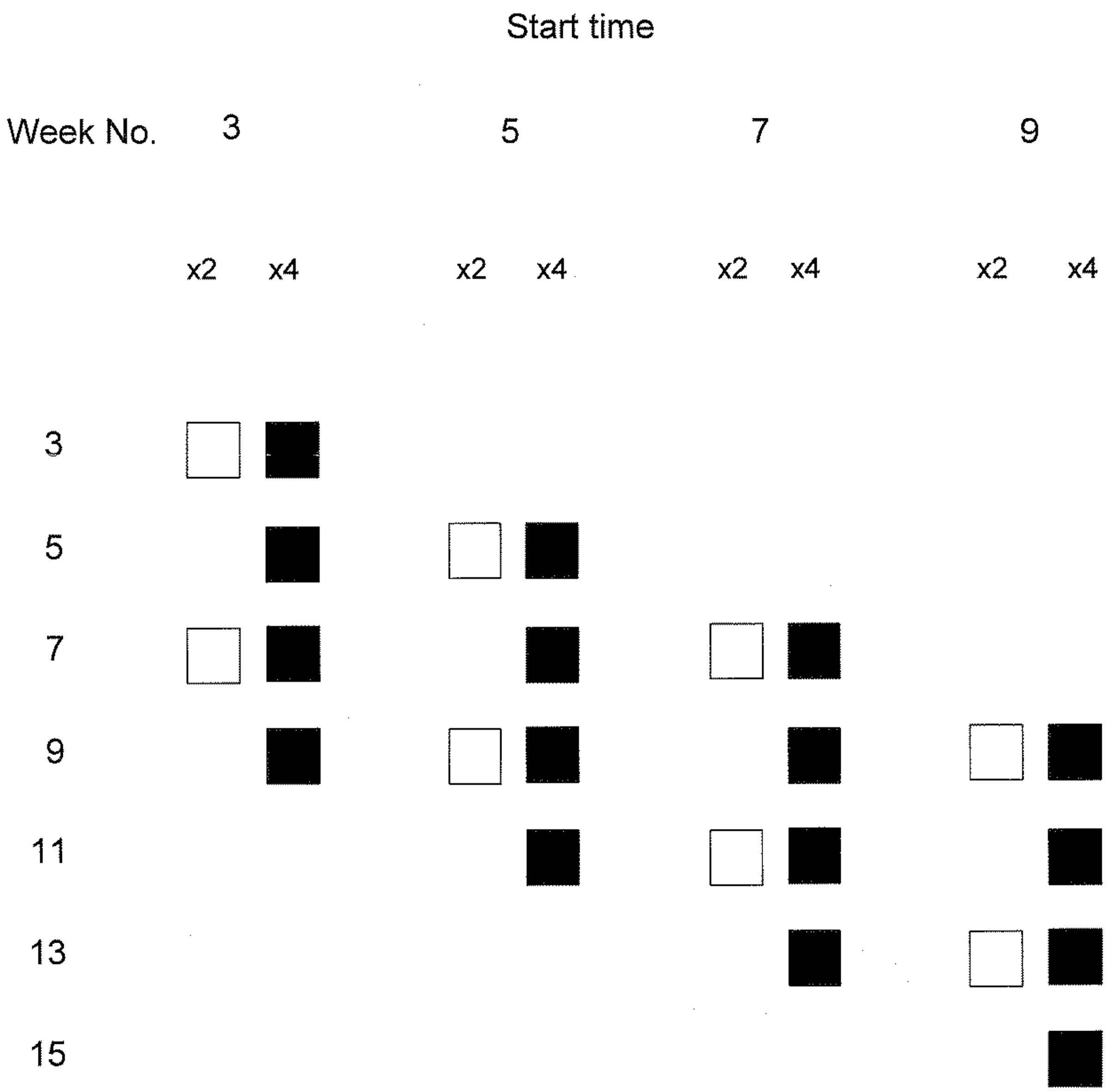
The low density control treatment was planted with 24 plants per double row while the high density control treatment was planted with 36 plants per double row. The low density control treatment represented the initial plant density at which all treatments were planted, while the high density control treatment represented the final plant density that was achieved when all side shoots had been added. These control treatments remained at the same initial planting densities throughout the experiment. The numbers of plants per double row can be converted to densities of plants per m^2 or per acre but, as the original areas were so small, the calculated densities are inevitably approximations.

Low density = (8k)	24 plants per double row, equivalent to approximately 2.037 plants m^{-2} (8250 plants per acre).
High density = (12k)	36 plants per double row, equivalent to approximately 3.056 plants m^{-2} (12 376 plants per acre).

4.2 Side-shoots

The double rows that were to receive side-shoot treatments were planted at an initial low density of 24 plants per double row. A total of 12 side shoots were then taken, one from every other plant, starting either in week 3, week 5, week 7, or week 9, to give the final density of 36 heads per double row. At each start time, two patterns of taking side shoots were employed. In one pattern, one half of the required number of side shoots was taken in the starting week and the other half was taken one month later. In the other pattern, one quarter of the required number of side shoots was taken in the starting week and the other three quarters were taken two, four, and six weeks later. These patterns are represented in Fig. 2. The plants that were to carry side shoots were identified with coloured strings before the treatments began and were so arranged, that even with different patterns of taking side shoots, the distribution of side shoots was as even as possible within each double row. The side shoots selected in week 3 were immediately below truss 4 while those selected in weeks 5, 7, 9, 11, 13, and 15 were immediately below trusses 6, 8, 10, 12, 14, and 16 respectively. Fruit from the first side shoot were picked in the week beginning 12 April (week 15). A timetable of the principal events is given in Appendix 1.

Fig. 2. The pattern of taking side shoots



5. Records

5.1 Fruit weight

Fruit were normally picked from every plot on three occasions each week, starting from 3 March (week 9); they were then assigned to Class I, II, or waste and Class I fruit were graded by size (B/C = >57mm; D = 47-57mm; E = 40-47mm; F = 35-40mm). The D size category was further divided into large D (D_L = 52-57mm) and small D (D_S = 47-52mm) categories. The details of the weight of fruit picked in successive four-week periods by Class and by grade, the proportions that each grade represented of Class I fruit, and the cumulative fruit yields in all Classes and grades are presented in Tables in Appendix 2.

5.2 Fruit numbers

The numbers of fruit picked from every plot in each size category of Class I and in Class II and waste were counted on each harvest occasion, so that mean fruit weights could be calculated for all classes and size categories. These are also presented in Appendix 2.

5.3 Side shoot development

The dates when side shoots were taken were recorded together with the day number when the first flower of the first truss of each side shoot reached anthesis, the day number when the first fruit of the first truss was picked, and the number of the main stem truss that was being picked at that time. From these data, the duration of development of the first fruit on the first truss of each side shoot was estimated, and also the time that elapsed between taking the side shoot and picking the first fruit from that side shoot.

6. Statistical Analysis

The fruit yield accumulated in different classes and size categories over successive four-week periods from the onset of fruit picking in week 9 (3 March) were subjected to Analysis of Variance. A preliminary analysis revealed that the pattern of taking side shoots had no significant effects either on yield or on average fruit weight. Consequently, the data from these two sub-treatments were pooled so as to give four replicates of each time of starting to take side shoots. This simplified further analysis of the data and increased the precision of the estimates of the effect of start time.

The further analysis first compared the yield from the high density control treatment with the average of the yields from the low density control and all of the side-shoot treatments: it then compared the yield from the low density control with the average of the yields from all of the side-shoot treatments, and finally, it then tested for the presence of either linear or quadratic trends when the means of the side-shoot treatments were ranked by start date, i.e. from week 3, through week 5 and week 7, to week 9.

Unfortunately, the nutrient circulating pump for plot 20 failed on 16 May (end of week 19) and, although the plants of this plot were without fresh nutrient for only a few hours, they took some weeks to recover, during which time their fruit yield was markedly reduced. From week 20 onwards, therefore, the actual yields of this plot were replaced on a harvest by harvest basis by missing plot values calculated by standard analysis of variance methods. Consequently, the cumulative yield for plot 20 (side shoots in week 7) is a mixture of actual and estimated yields.

RESULTS

1. Environments

1.1 Solar radiation

The average amount of solar radiation incident on the glasshouse per day in each successive week was variable but generally, it increased from week 1, reached a peak value of 24.5 MJ m^{-2} d^{-1} in week 25, and then gradually declined again (Fig. 3). Measurements made with a Kipp solarimeter mounted inside the glasshouse, indicated that, on average, 60% of the available solar radiation was transmitted into the glasshouse over the duration of the experiment.

1.2. Temperature

Average temperatures rose gradually from about 17.5°C in the early part of the year to 21°C in week 26 and then declined again (Fig. 4). In general, the changes in average temperature closely followed the changes in solar radiation (Fig. 3).

1.3. CO_2 concentration

The average daily CO_2 concentration was 926 vpm up to the end of week 14 (11 April), after which it declined and, from week 16 (19 April) until the end of the experiment, the average daily concentration was 448 vpm (Fig. 5).

1.4 Monthly solar radiation

All yield data are presented in terms of yield of fruit picked in successive four-week periods and so, for comparison, the average amount of solar radiation incident on the glasshouse per day has also been presented as averages over successive four-week periods (Fig. 6).

Fig. 3. The average daily quantity of solar radiation incident on the glasshouse per week in 1993

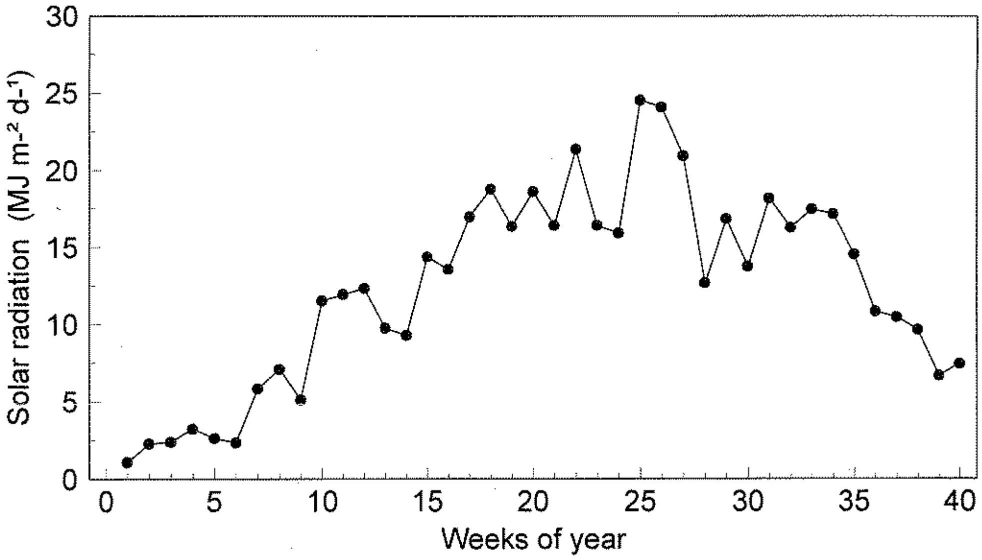


Fig. 4. The average daily 24-hour temperature in the glasshouse per week in 1993

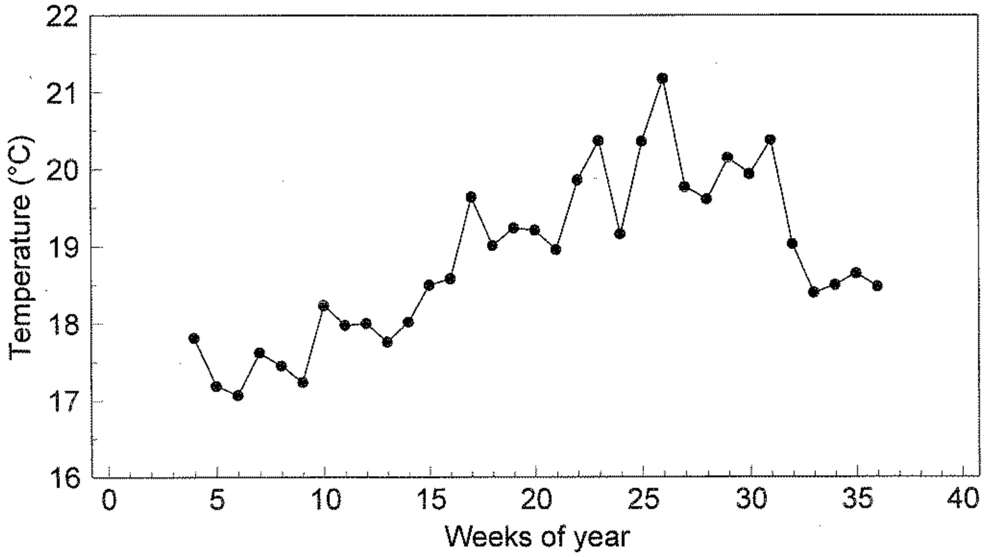


Fig. 5. The average daytime CO2 concentration in the glasshouse per week in 1993

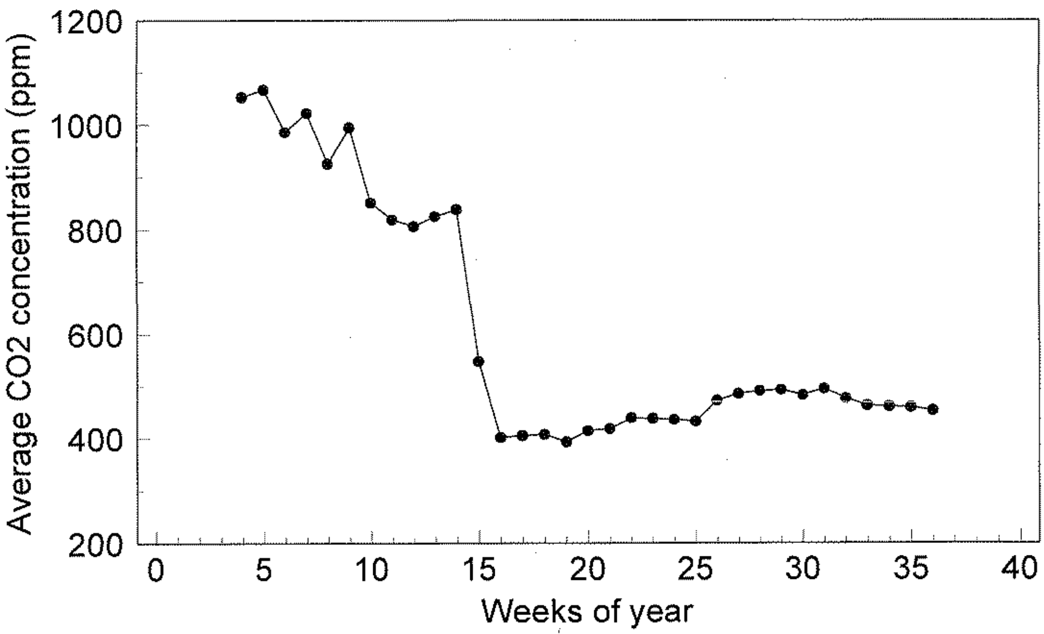
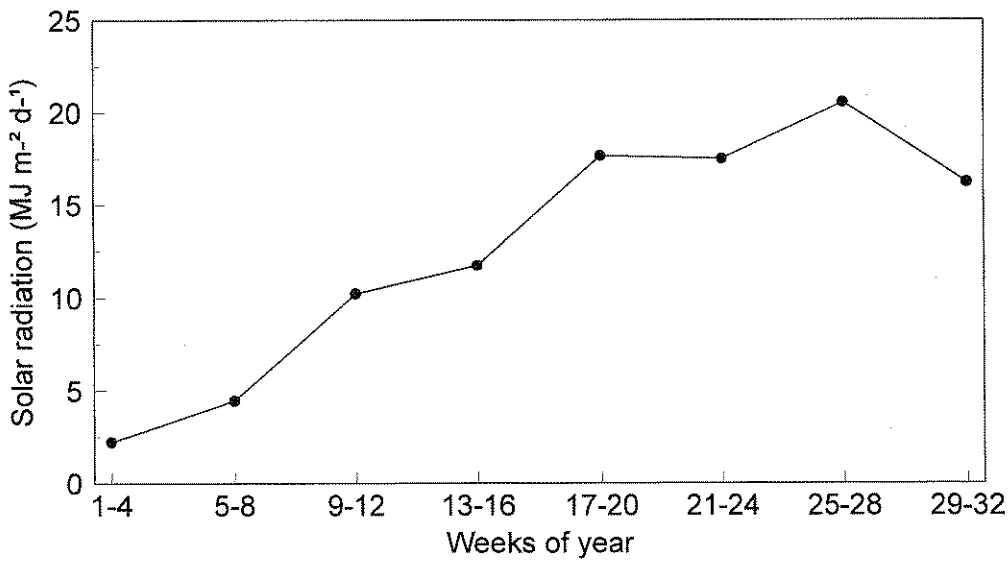


Fig. 6. The average daily quantity of solar radiation incident on the glasshouse per four-week period in 1993



2. Effects of the pattern of taking side shoots

It did not seem to matter whether the required number of side shoots was taken either in two batches each one month apart or in four batches each two weeks apart for there were no significant differences between these treatments in either yield or in average fruit size. In all subsequent analyses, therefore, the data from these two sub-treatments have been pooled.

3. The development of side shoots

The development of side shoots was recorded in terms of the date when they were taken, the date of anthesis of the first flower of the first truss of each side shoot, and the date when the first fruit was picked from the first truss.

The first flower of the first truss of side shoots taken in week 3 (Day 74) reached anthesis at the end of week 5 (Day 94) and the first fruit were picked from this side shoot in week 15 (Day 162). From the data summarised below it can be seen that the first fruit took about 67 days to develop from anthesis to picking and that 88 days had to elapse before the side shoots that were taken in week 3 began to contribute to fruit yield. Fruit developed a little faster (62 days) when side shoots were taken in week 5 but the overall time from taking the side shoot until it contributed to yield was only slightly reduced (86 days). This period was shortened further (84 days) when side shoots were taken in week 7 and was reduced to 81 days when they were taken in week 9. The acceleration of development that occurred when side shoots were taken later than week 3 was probably due to increases in average temperature that were associated with increasing week number (Fig. 4). In the previous experiment (HDC PC65), side shoots that were taken in week 9 began to produce fruit about 75 days later. This difference between experiments probably reflects the fact that side shoots were selected at a very early stage of development in the current experiment.

In summary, therefore, side shoots taken in week 3 produced marketable fruit from week 15 onwards (Day 162), those taken in week 5 did so from week 17 (Day 174), those taken in week 7 did so from the start of week 19 (Day 186), while those taken in week 9 produced marketable fruit from week 20 onwards (Day 197) (see also Appendix 1).

Side shoot development

Treatment	Day side shoot taken (T)	First truss				Main stem truss being picked
		Day of anthesis (A)	Day of pick (A)	Days to develop (P-A)	Take to harvest (P-T)	
Week 3	74	94.2	161.5	67.3	87.5	6.3
Week 5	88	112.7	174.4	61.7	86.4	8.2
Week 7	102	127.6	186.1	58.5	84.1	10.0
Week 9	116	138.7	196.8	58.2	80.8	11.8

4. Marketable yield

The control treatment planted at high density produced a greater weight of marketable fruit in most four-week periods than that planted at low density (Fig. 7; Table 1). The difference between these control treatments became more marked with time and by week 32, the cumulative yield of marketable fruit was 7.8% greater in the high density control (Table 2).

Although in weeks 9-12, marketable yield was higher when side shoots were taken in week 3, the presence of side shoots had little consistent effect on marketable yield up to week 20. Thereafter, the yield from the side-shoot treatments tended to be greater than from the low density control and by weeks 29-32 it was significantly greater. In the four-week period from weeks 29-32, the marketable yield from the side-shoot treatments was similar to that from the high density control (Fig. 8; Table 1). Within the side-shoot treatments in this four-week period, there were significant linear and quadratic trends in marketable yield such that the highest yield was obtained when side shoots started to be taken in week 9 (Table 1). These trends were not significant in the final cumulative yields. On average, the final cumulative yield of all the side-shoot treatments (i.e. 34.88 kg m^{-2}) was 1.8% less than from the high density control but 4.4% more than from the low density control (Table 2).

5. Class I and Class II yield

The differences between the high and low density control treatments in yield of Class I fruit (Fig. 9; Table 3) were greater than for marketable yield and, by week 32, the cumulative yield of Class I fruit from the high density control was 13.5% more than from the low density control (Table 4). The reason for this enhanced difference was the greater production of Class II fruit in the low density control (Fig. 11; Table 5). By week 32, the cumulative yield of Class II fruit (Table 6) as a proportion of marketable yield was 12.3% in the low density control but was only 7.6% in the high density control.

The average yield of Class I fruit from all the side-shoot treatments was significantly lower than from the high density control in weeks 9-12 (Fig. 10; Table 3) but, by weeks 17-20 and 21-24, once the side shoots began to contribute to fruit yield, it was now no different from the high density control and was instead, significantly different from the low density control. In some four-week periods there was also a significant linear trend within the side-shoot treatments with the highest yield associated with the earliest time of taking side shoots, i.e. week 3. The cumulative data (Table 4) showed that the high density control produced the highest yield of Class I fruit, up to week 24. By week 32, however, the average cumulative yield from all of the side-shoot treatments was no different from that of the high density control but was significantly greater than that of the low density control and there was still a significant linear trend within the means of the side-shoot treatments such that the highest yield of Class I fruit was in the week 3 treatment. The presence also of a quadratic trend might indicate that taking side shoots as late as week 9 was superior to taking them in week 7.

In general, the effects on the yield of Class II fruit produced by initial planting density and by taking side shoots (Figs 11 and 12; Tables 5 and 6) were the opposite to those on Class I fruit yield: more Class II fruit were produced by the low density control and by starting to take side shoots later than week 3, especially when starting in week 9.

Fig. 7. The effects of initial planting density on yield of marketable fruit

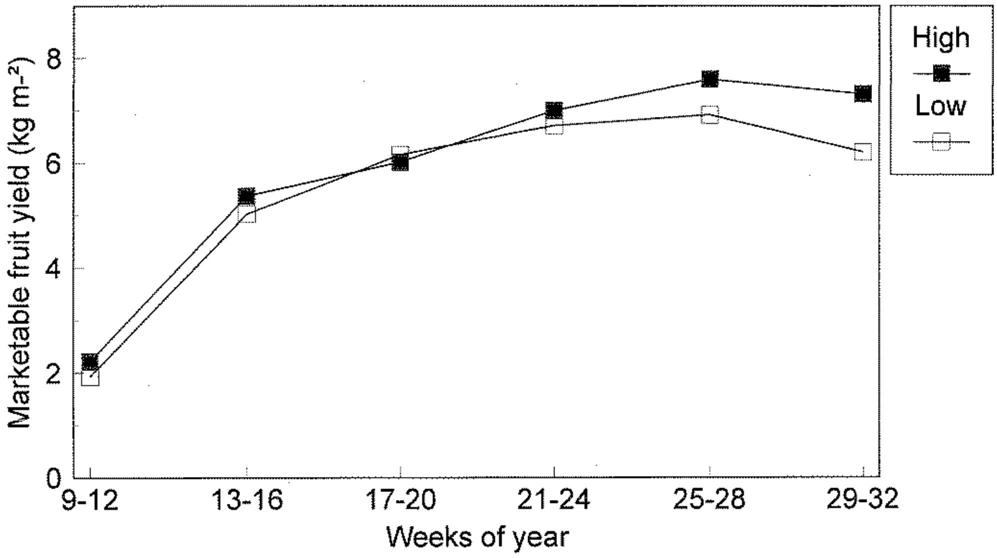


Fig. 8. The effects of time of taking side shoots on yield of marketable fruit

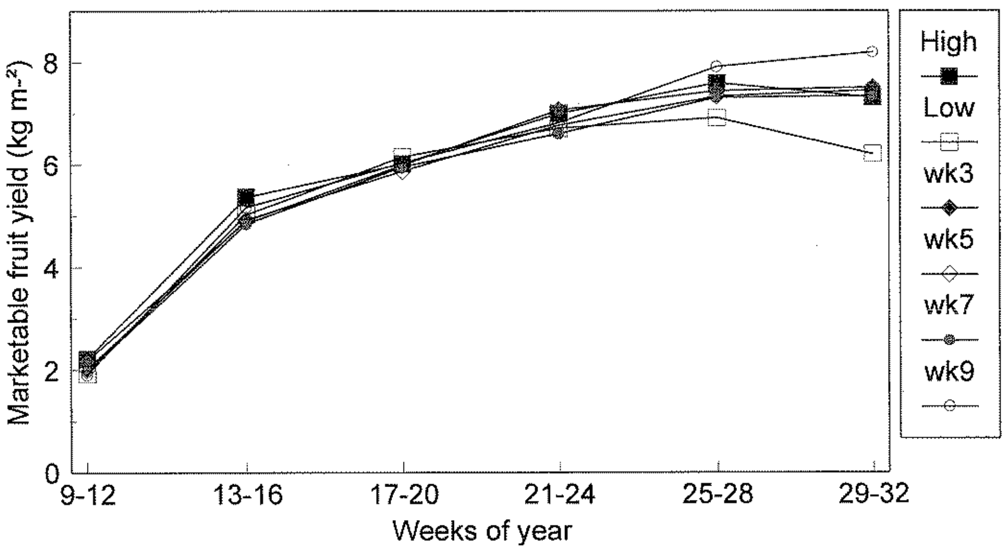


Fig. 9. The effects of initial planting density on yield of Class I fruit

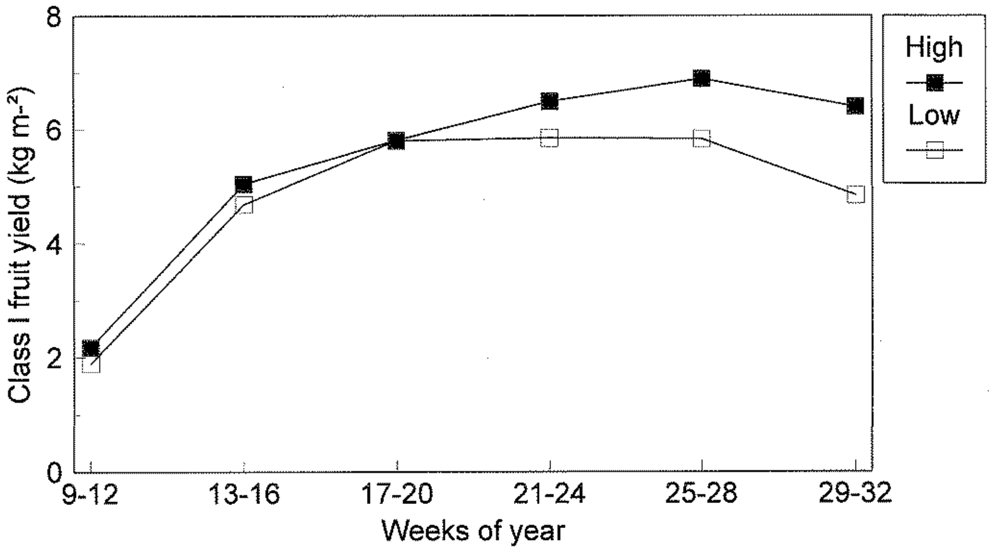


Fig. 10. The effects of time of taking side shoots on yield of Class I fruit

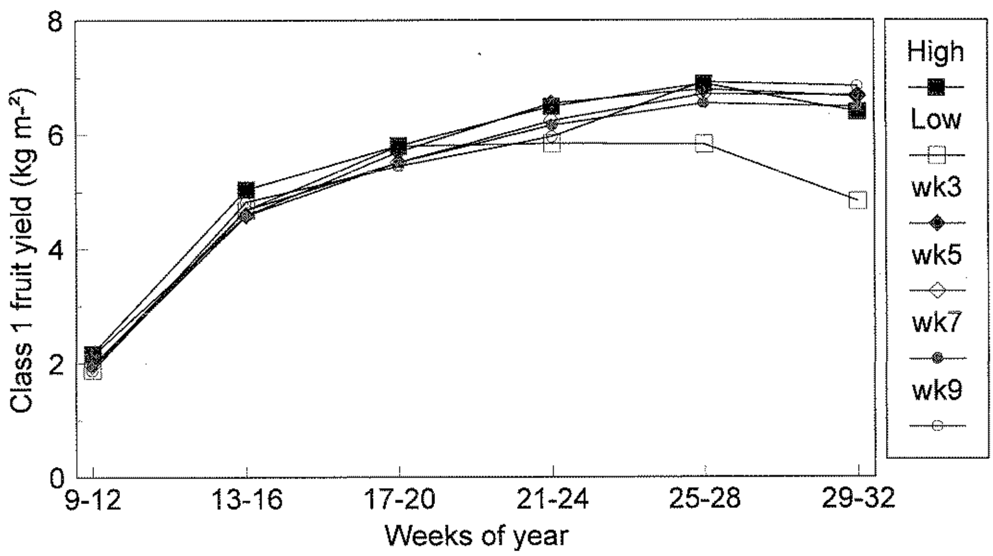


Fig. 11. The effects of initial planting density on yield of Class II fruit

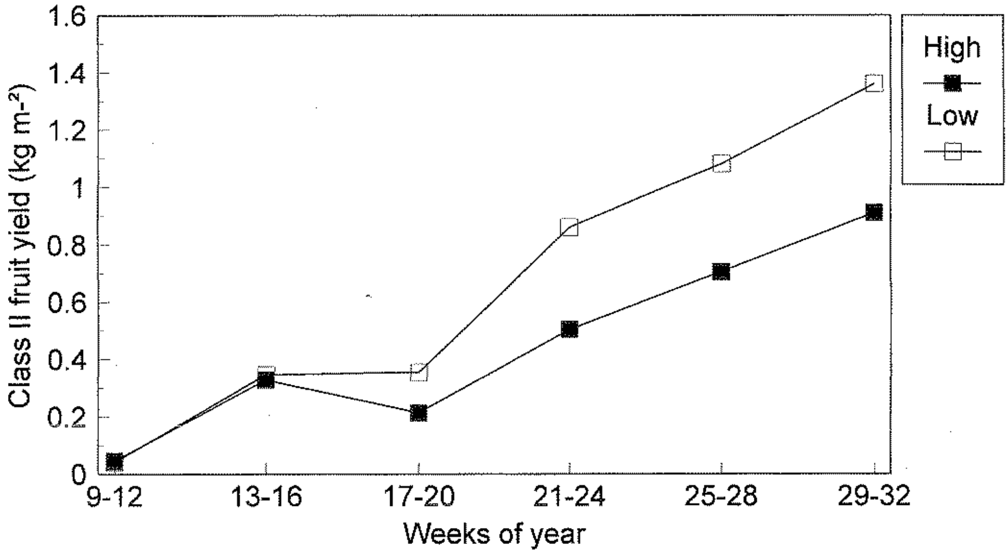
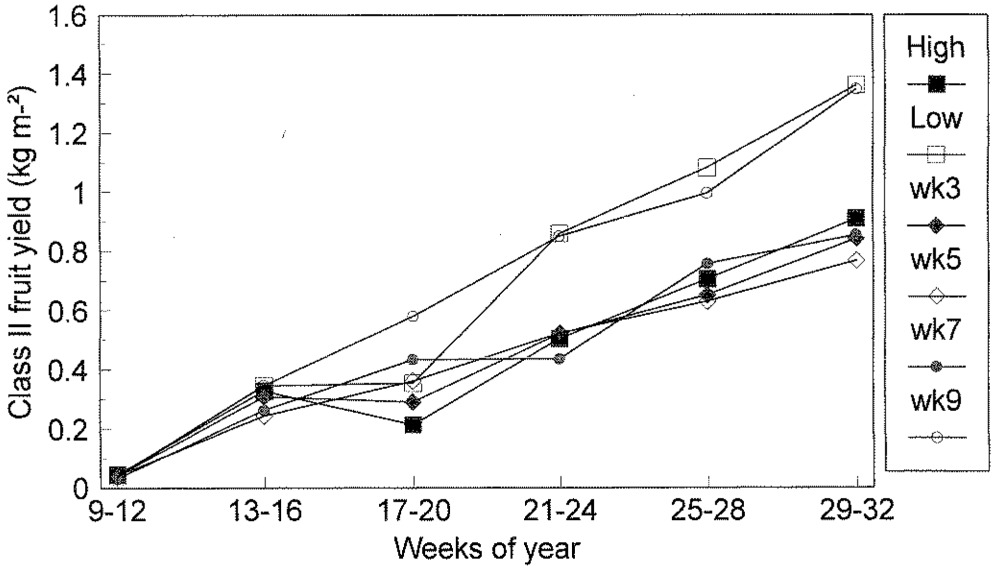


Fig. 12. The effects of time of taking side shoots on yield of Class II fruit



6. Fruit number

The number of marketable fruit produced by the two control treatments in each four-week period (Fig. 13) increased more than twofold between weeks 9-12 and 13-16 but, whereas the number continued to increase steadily up to weeks 29-32 in the high density control, the number produced by the low density control did not increase after weeks 17-20 (Fig. 13; Table 7). The high density control always produced significantly more fruits than the low density control in all four-week periods. Indeed, the total number of fruit picked per m^2 by week 32 from the high density control (524) was 28.5% more than from the low density control (404) but, as there were 50% more plants per m^2 in the high density control, the number produced by each plant was 14% less (Table 8), implying that there were fewer fruit set per truss in the high density control. Comparison of the numbers of fruit picked from the low and high density controls in each four-week period indicate that those trusses picked from the high density control in weeks 17-20 (Table 8) were relatively worst affected.

Further evidence of lack of fruit set at high density came from counts of the number of marketable fruits set on each of the first six trusses, i.e. excluding small fruit that would be classed as waste (see Table below). These counts, made on eight plants of each treatment in each compartment, showed that the control plants at high density generally set 1.06 fewer marketable fruit on each of the first six trusses, i.e. a reduction of 15.1%.

Number of marketable fruit set per truss per plant

Truss No.	High density	Low density	High/Low
1	5.38	8.58	0.63
2	6.00	7.04	0.85
3	4.83	6.04	0.80
4	6.25	7.33	0.85
5	6.54	7.21	0.91
6	6.83	6.00	1.14
Mean	5.97	7.03	0.85

The effect of starting to take side shoots in week 3 was to increase significantly the numbers of fruit picked in weeks 17-20 and 21-24 relative to starting to take side shoots in week 9 (Fig. 14; Table 7). By weeks 21-24 onwards, the average number of fruit picked from all side-shoot treatments was significantly greater than the number picked from the low density control and, by weeks 25-28 onwards, it was similar to the number picked from the high density control.

The patterns of production of Class I fruit (Figs 15 and 16; Table 9) were similar to those for marketable fruit (Figs. 13 and 14), although the total numbers were 7.7% less at high density and 12.4% less at low density. Consequently, the differences between the two control treatments were accentuated.

Fig. 13. The effects of initial planting density on the number of marketable fruit picked per m²

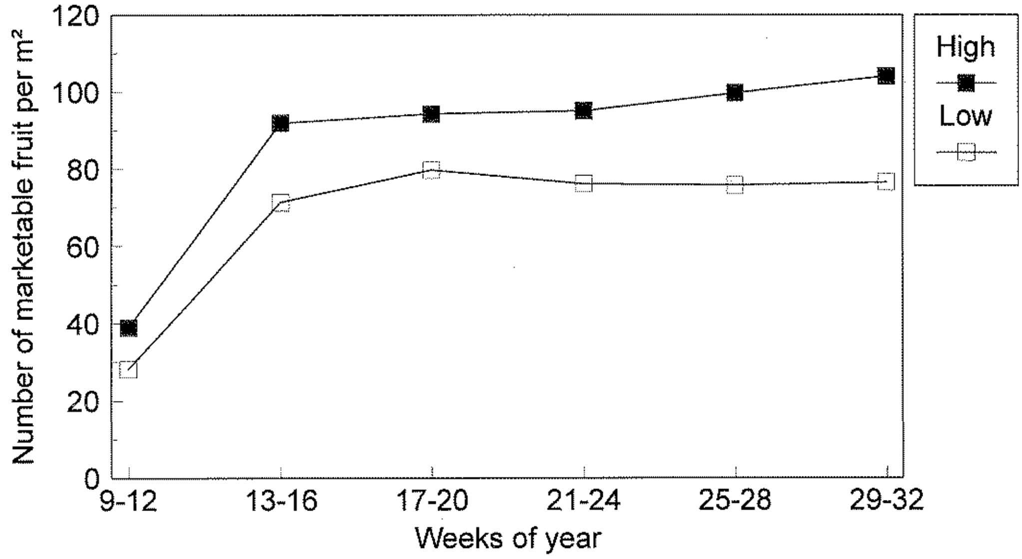


Fig. 14. The effects of taking side shoots on the number of marketable fruit picked per m²

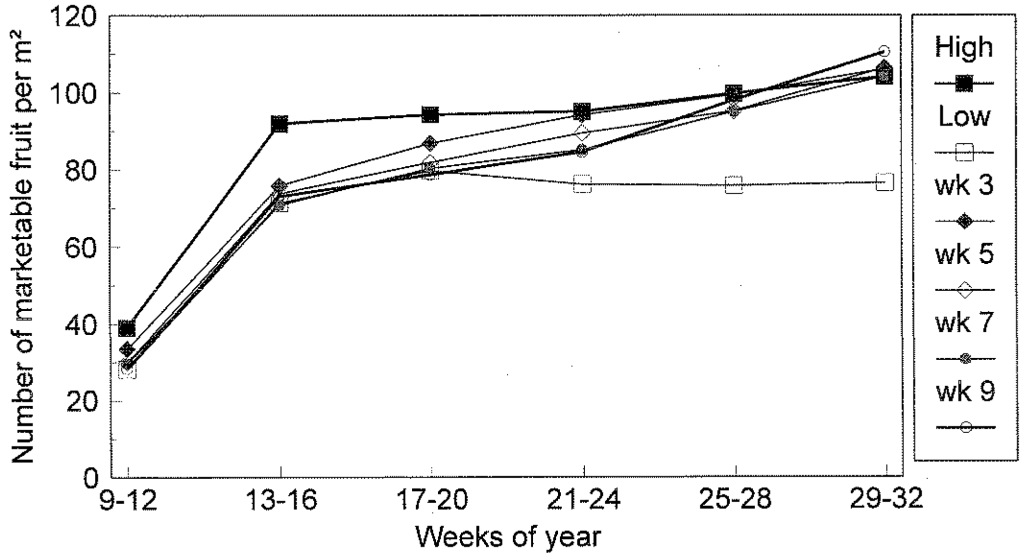


Fig. 15. The effects of initial planting density on the number of Class I fruit picked per m²

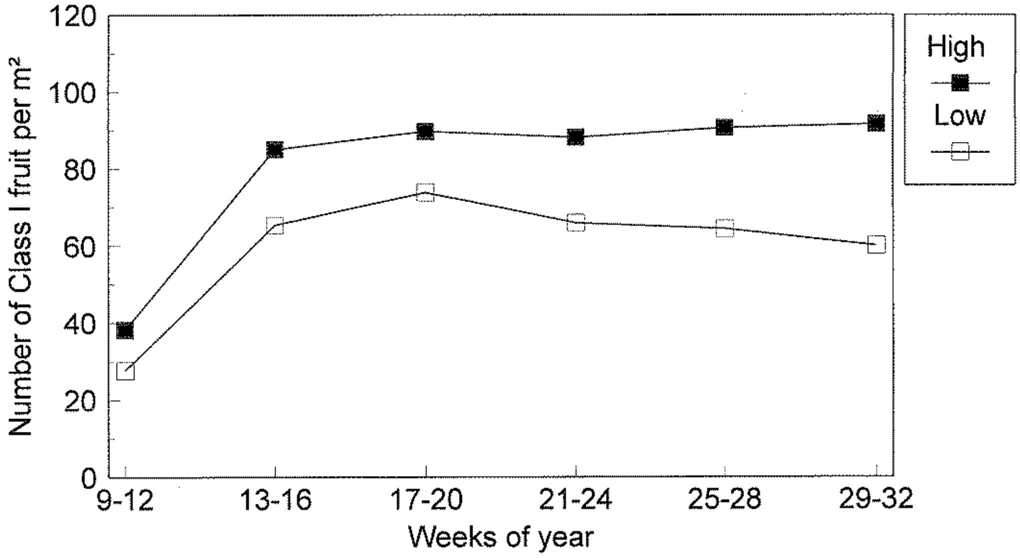
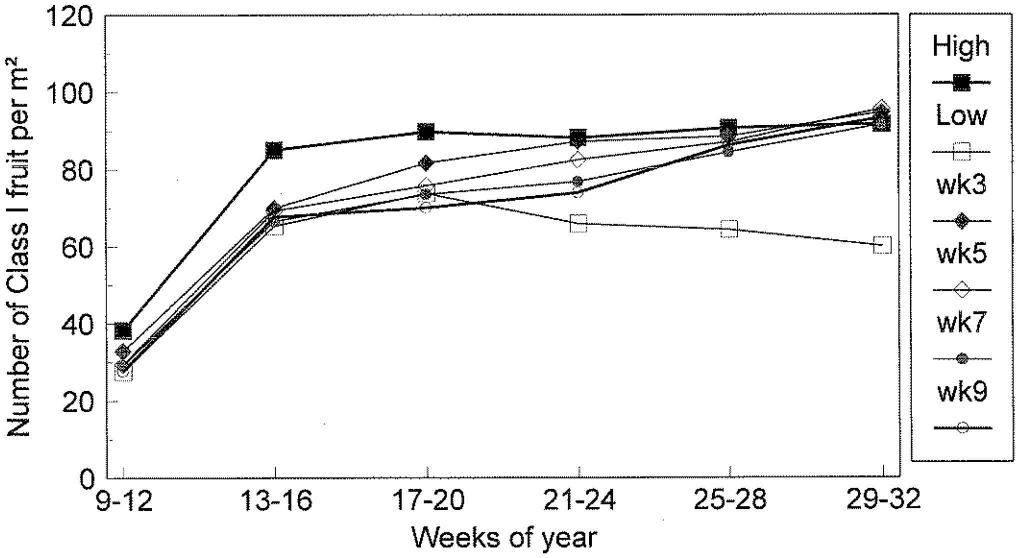


Fig. 16. The effects of taking side shoots on the number of Class I fruit picked per m²



7. Mean fruit weight

The separate effects of treatment and environment on yield of fruit and on fruit number that have already been described, come together to influence mean fruit weight. For comparison with commercial assessments, mean fruit weight has been computed as the average of all Class I fruit.

In both control treatments, the mean Class I fruit weight steadily increased in each successive four-week period up to weeks 25-28, after which it declined again (Fig. 17; Table 10). In weeks 9-12, 13-16, and 17-20, fruit number was larger in the high density control than the low density control and so, as the yields of the two treatments were relatively similar in these three periods, mean fruit weight was significantly smaller in the high density control. In later periods, although there were differences between the two treatments in yield, the differences in fruit number were still proportionally greater and so mean fruit weight of the high density control remained significantly lower than that of the low density control. In general, the mean fruit weight of the high density control was 16 to 17% less than that of the low density control.

The addition of side shoots had no significant impact on mean fruit weight at the start of picking (weeks 9-12) but, by weeks 13-16, the mean fruit weight averaged over all the side-shoot treatments was significantly smaller than that of the low density control but significantly larger than that of the high density control (Fig. 18; Table 10). Furthermore, there was an obvious gradient within the means of the side-shoot treatments such that the smallest mean fruit weight occurred when side shoots were taken early (week 3), while the largest occurred when they were taken late (week 9). These patterns were maintained in all subsequent four-week periods up to, and including, weeks 25-28. By weeks 29-32, the mean fruit weights of all the side-shoot treatments were similar to that of the high density control. These patterns became even clearer when the mean fruit weights of the different treatments were expressed as a proportion of that in the low density control (Figs. 19 and 20).

The mean fruit weight reflects the relative contributions of fruit in different size grades and the effects of treatment and of environment on the distribution of yield between the different size grades are shown in the following sections.

Fig. 17. The effects of initial planting density on mean fruit weight

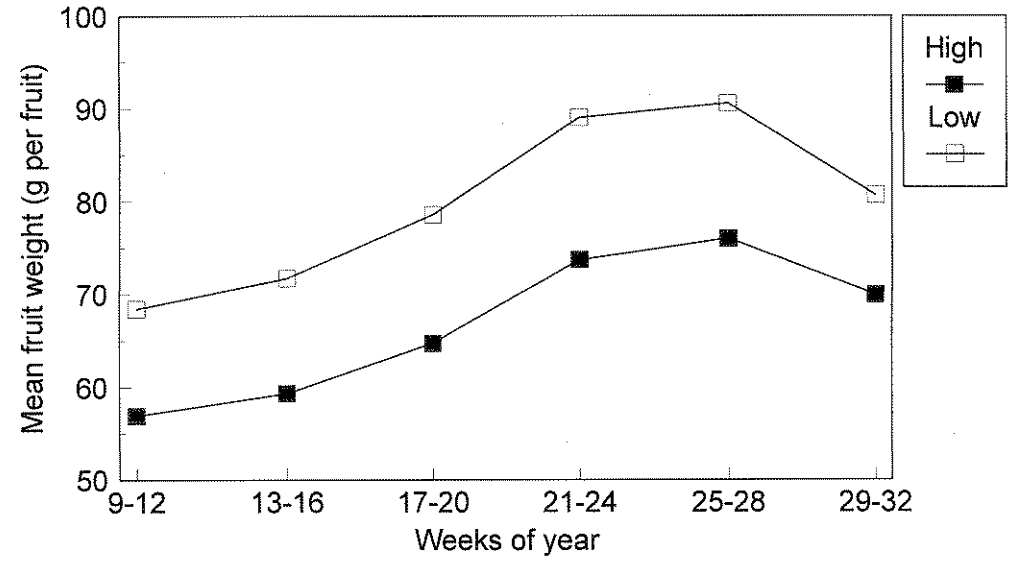


Fig. 18. The effects of time of taking side shoots on mean fruit weight

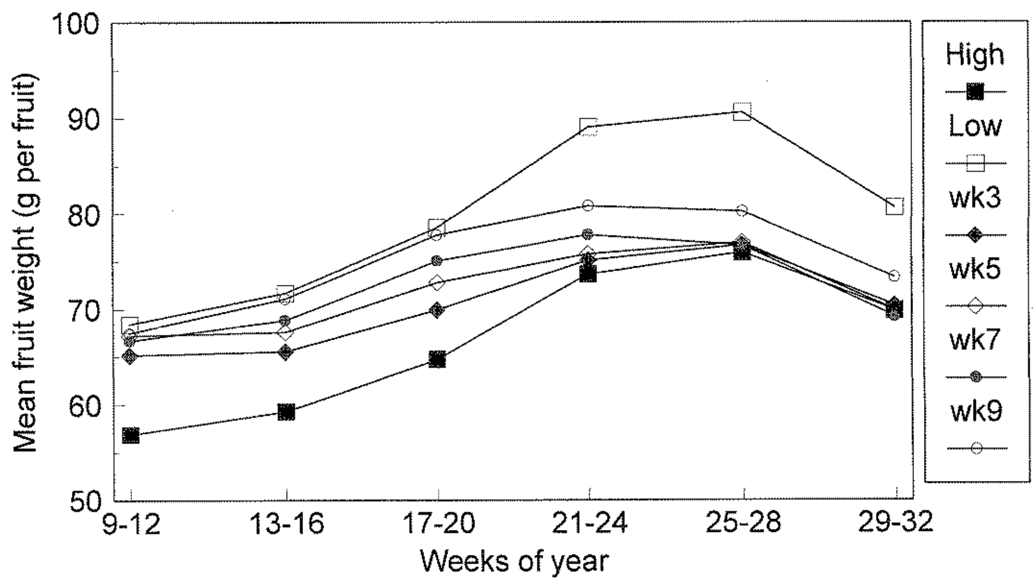


Fig. 19. The effects of initial planting density on mean fruit weight relative to the low density control

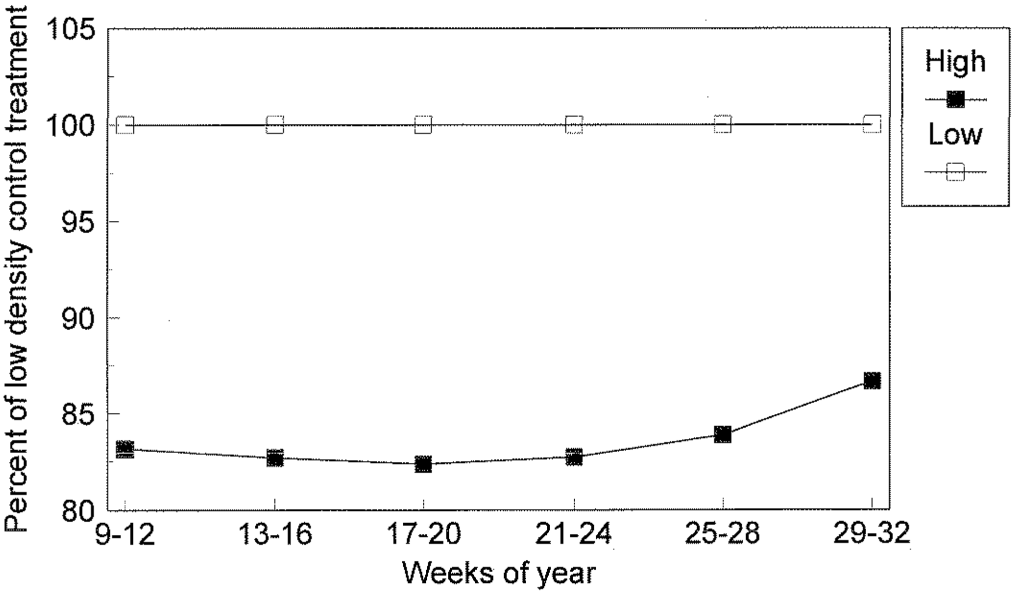
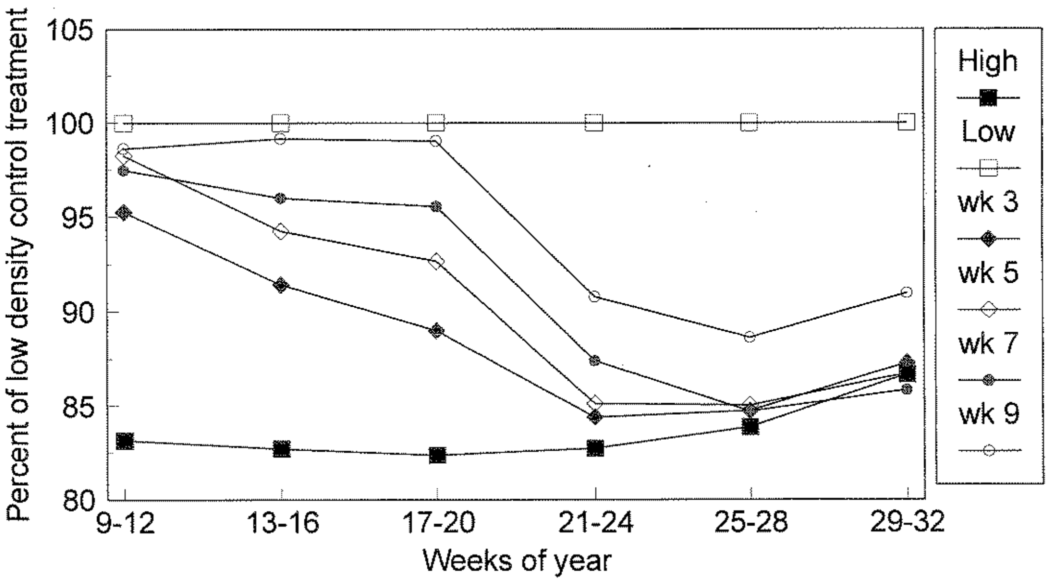


Fig. 20. The effects of time of taking side shoots on mean fruit weight relative to the low density control



8. Grade D fruit

8.1 Yield of grade D fruit

The high density control treatment produced a significantly smaller yield of D grade fruit than the low density control in the first four weeks of production, but then produced a significantly greater yield from weeks 21-24 onwards (Fig. 21; Table 11). The side-shoot treatments also outyielded the low density control from weeks 21-24 onwards but, whereas up to weeks 21-24 there was generally a significant linear trend with the highest yield associated with starting to take side shoots in week 3, this trend was not apparent in weeks 25-28 and 29-32 (Fig. 22; Table 11).

The high density control, together with all of the side-shoot treatments, had produced a larger cumulative yield of grade D fruit than the low density control by week 24 and they continued to do so for the remainder of the experiment (Table 12). Also, up to week 28, the largest cumulative yield of grade D fruit from side-shoot treatments was associated with starting to take side shoots as early as week 3 (Table 12).

8.2 Proportion of Class I fruit

The proportion of Class I fruit that were of grade D declined from about 88% in weeks 9-12 to just 52% in weeks 21-24 in the low density control treatment; it then increased again to about 83% by weeks 29-32 (Fig. 23; Table 13). In the high density control, about 70% of the Class I fruit were of grade D in each four week period up to weeks 21-24 but then the proportion increased and had reached almost 91% in weeks 29-32. With the side-shoot treatments, this proportion followed similar trends to the low density control in the early part of the season but was more like the high density control in the later part of the season (Fig. 24; Table 13).

On average, over the whole period of the experiment, the high density control and all of the side-shoot treatments produced about 80% of their Class I fruit in grade D, while the proportion in the low density control (69%) was significantly less.

8.3 Yield of grade D_L fruit

The heaviest yield of large grade D fruit was initially from the low density control but, in weeks 21-24 and 25-28, this treatment produced the lowest yield (Fig. 25; Table 14). On the other hand, yields from the side-shoot treatments were similar to the low density control up to weeks 17-20 but, from then on, were similar to the high density control (Fig. 26; Table 14). Consequently, the side-shoot treatments all produced significantly greater cumulative yields of grade D_L fruit than either of the control treatments (Table 15). Within the side-shoot treatments, starting to take side-shoots in week 9 produced the largest yield in the last four-week period and had the largest cumulative yield by the end of the experiment (Table 15).

8.4 Yield of grade D_S fruit

In the small grade D fruit category, the low density control always produced a smaller yield than the high density control (Fig. 27; Table 16) and, by weeks 21-24, consistently produced a smaller yield than the average of all the side-shoot treatments (Fig. 28; Table 16). The means of the side-shoot treatments usually demonstrated a linear trend with the highest yield associated with starting to take side shoots in week 3. The cumulative data (Table 17) showed that the high density control produced the greatest weight of grade D_S fruit, followed by the treatment in which side shoots started to be taken in week 3, while the lowest yield was produced by the low density control.

Fig. 21. The effects of initial planting density on yield of Grade D fruit

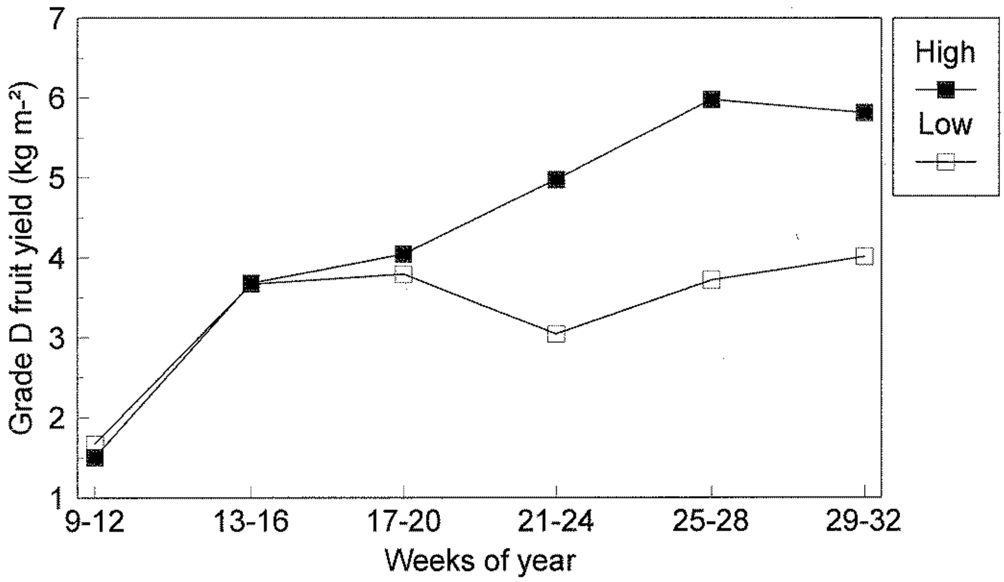


Fig. 22. The effects of time of taking side shoots on yield of Grade D fruit

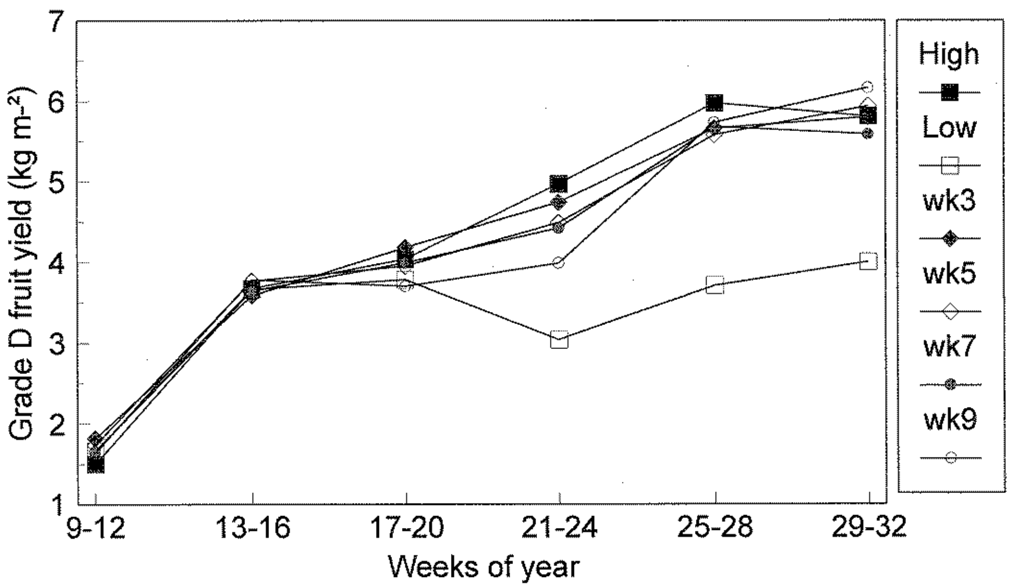


Fig. 23. The effects of initial planting density on the proportion of Class I fruit that are grade D

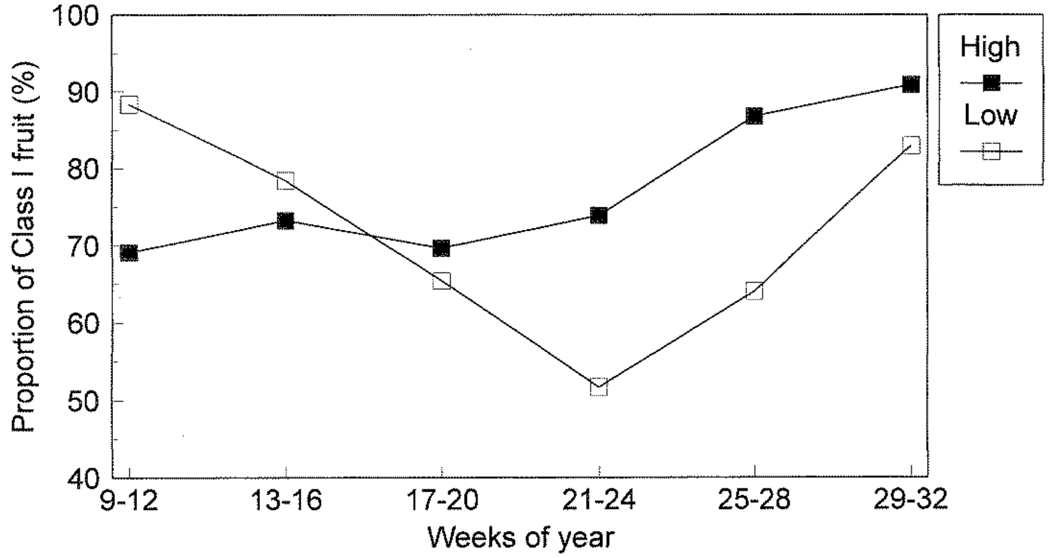


Fig. 24. The effects of time of taking side shoots on the proportion of Class I fruit that are grade D

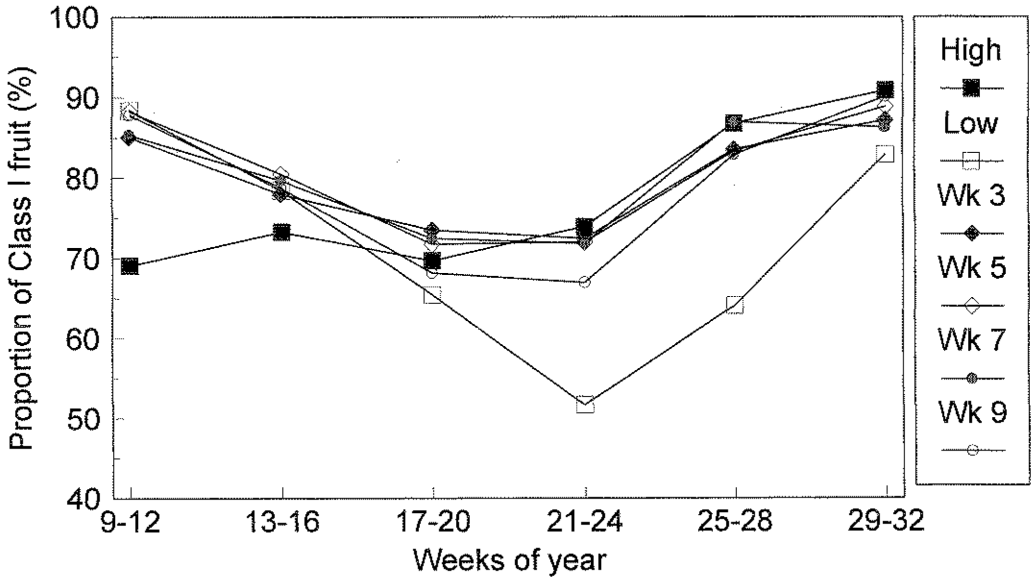


Fig. 25. The effects of initial planting density on yield of Grade DL fruit

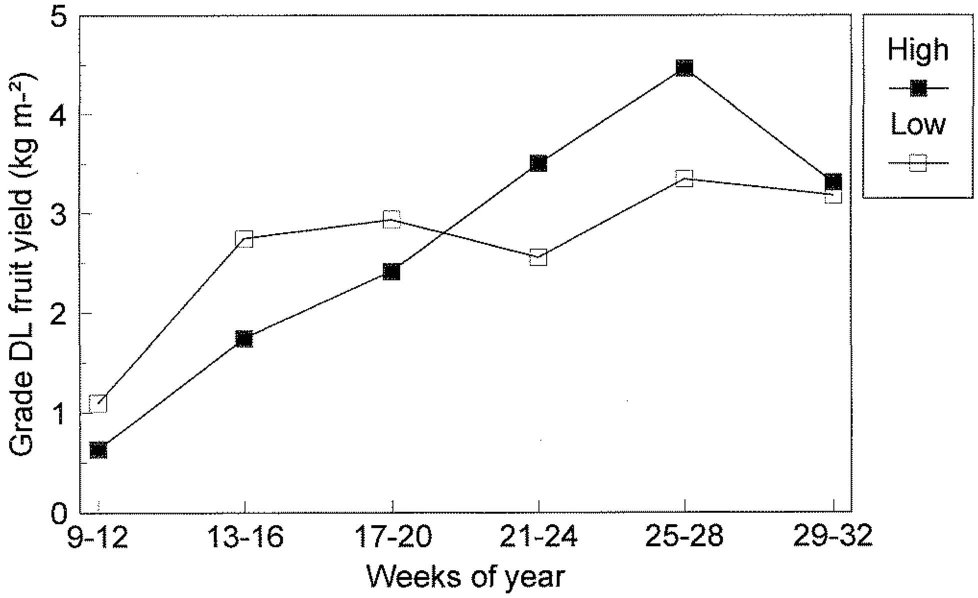


Fig. 26. The effects of time of taking side shoots on yield of Grade DL fruit

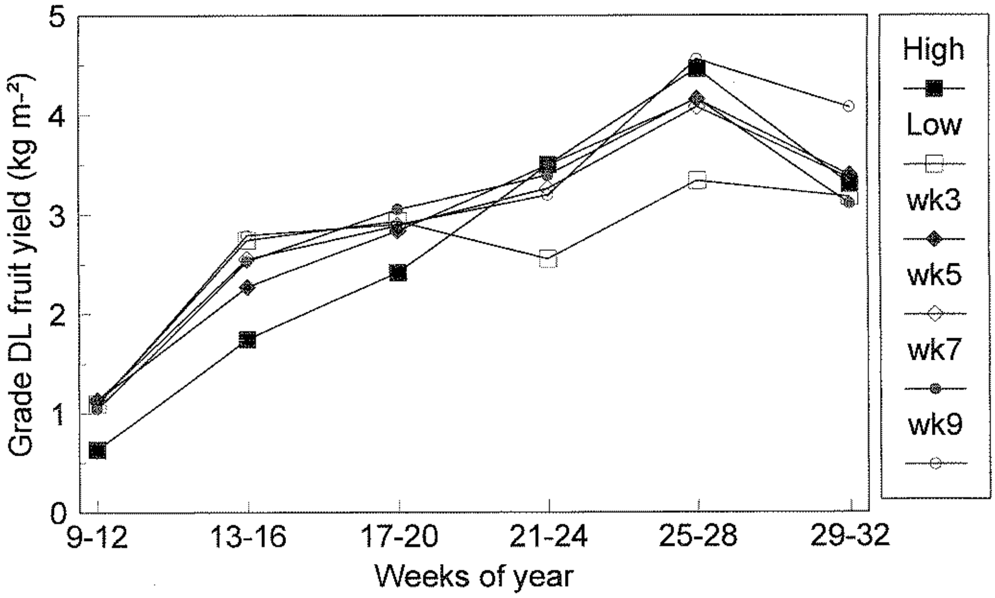


Fig. 27. The effects of initial planting density on yield of grade Ds fruit

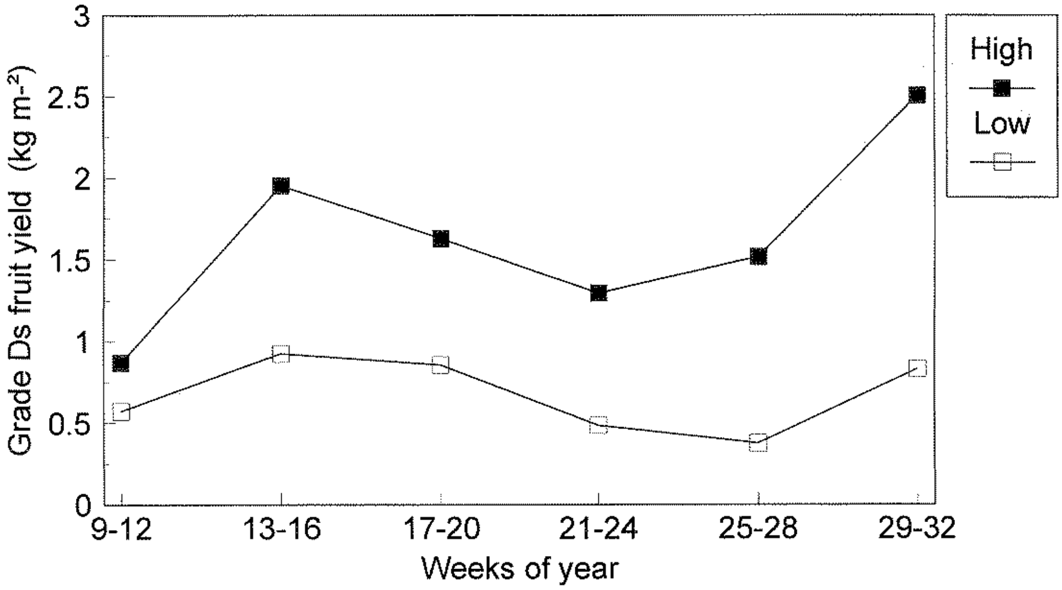
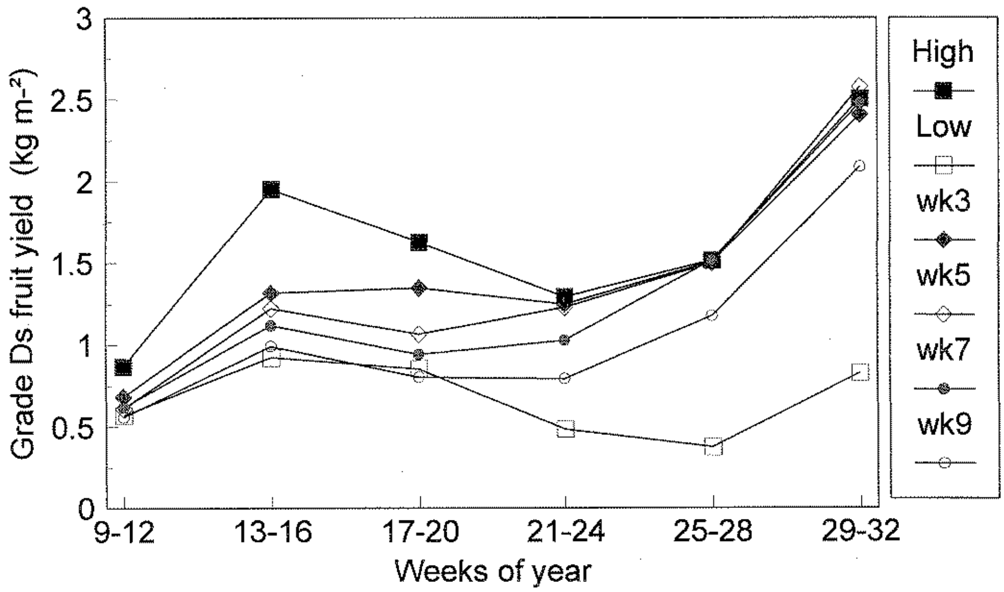


Fig. 28. The effects of time of taking side shoots on yield of Grade Ds fruit



9. Grade C fruit

9.1 Yield of grade C fruit

Both control treatments produced their highest yield of grade C fruit in weeks 21-24 but the yield from the low density control was more than double that from the high density control in that period (Fig. 29; Table 18). The yield from the low density control was generally higher than from the high density control in all four-week periods from weeks 17-20 onwards. Consequently, the cumulative yield from the low density control was substantially greater (Table 19).

The yield of grade C fruit from the side-shoot treatments was generally lower than from the low density control (Fig. 30; Table 18) but the mean cumulative yields from these treatments frequently showed a linear trend with the highest yield associated with starting to take side shoots in week 9 (Table 19).

9.2 Proportion of Class I fruit

The proportion of Class I fruit that were in grade C was highest in the low density control in all periods (Fig. 31; Table 20) and, within the side-shoot treatments, it was highest when side shoots started to be taken in week 9 (Fig. 32; Table 20). By the end of the experiment, while an average of 26% of all Class I fruit were in grade C in the low density control, the proportion was less than 8% in the high density control (Table 20). Amongst the side-shoot treatments, all were significantly different from both the high and low density controls but starting to take side shoots in week 9 produced the highest proportion (15%), and starting in week 3 produced the lowest proportion (10%) of grade C fruit.

10. Grade E fruit

10.1 Yield of grade E fruit

The smallest yield of grade E fruit was produced from the low density control in all four-week periods (Fig. 33; Table 21) and the greatest difference between the two control treatments was registered in the early part of the season, between weeks 13-16 and 17-20. The addition of side shoots increased the yield of grade E fruit in all four-week periods; the largest increase was associated with starting to take side shoots in week 3 and the smallest increase with starting to take side shoots in week 9 (Fig. 34; Table 21).

The final cumulative yield of grade E fruit from the high density control was more than double that from the low density control and the yield of both controls was significantly different from the average yield from all side-shoot treatments (Table 22). The final cumulative yields of the latter treatments were strongly graded from starting to take side shoots in week 3, which gave the highest yield, to starting to take side shoots in week 9, which gave the lowest yield.

10.2 Proportion of Class I fruit

The highest proportion of grade E fruit (27%) was produced by the high density control in the first weeks of picking (weeks 9-12), while the lowest proportion (1%) was produced by the low density control in weeks 25-28 (Fig. 35; Table 23). Overall, the final cumulative yield of grade E fruit accounted for 12.9% of the Class I fruit production to week 32 in the high density control, and 4.5% in the low density control. The addition of side shoots significantly increased the proportion of grade E fruit, relative to the low density control, from weeks 13-16 onwards, but the proportion did not reach that of the high density control until weeks 25-28 (Fig. 36, Table 23). In most four-week periods, the highest proportion of grade E fruit within the side-shoot treatments occurred when they started to be taken in week 3. In weeks 29-32, however, the highest proportion occurred when side shoots started to be taken in week 7 and this gave rise to a significant quadratic effect in this period.

When summed over the whole period of the experiment, no side-shoot treatment produced more than 10% grade E fruit, but there was a pronounced linear trend within these treatments; the highest proportion came from starting to take side shoots in week 3 and the lowest proportion from starting in week 9 (Table 23).

11. Leaf area

The length and breadth of selected leaves from plants in the low and the high density control treatments and on the main stem of the week 5 side-shoot treatment were measured at the end of the crop's life (week 38). The selected leaves were the leaf immediately below the truss at anthesis and the leaf immediately below each of the six successively older trusses. These measurements were made on eight plants of each treatment in each compartment and the average results are shown below.

Leaf length x breadth (cm^2)

Leaf below truss	High density	Low density	Week 5
Anthesis (A)	472	421	476
A-1	1001	904	994
A-2	1300	1114	1352
A-3	1441	1305	1477
A-4	1612	1343	1408
A-5	1604	1381	1442
A-6	1567	1340	1404
Total	8997	7804	8553

Fig. 29. The effects of initial planting density on yield of Grade C fruit

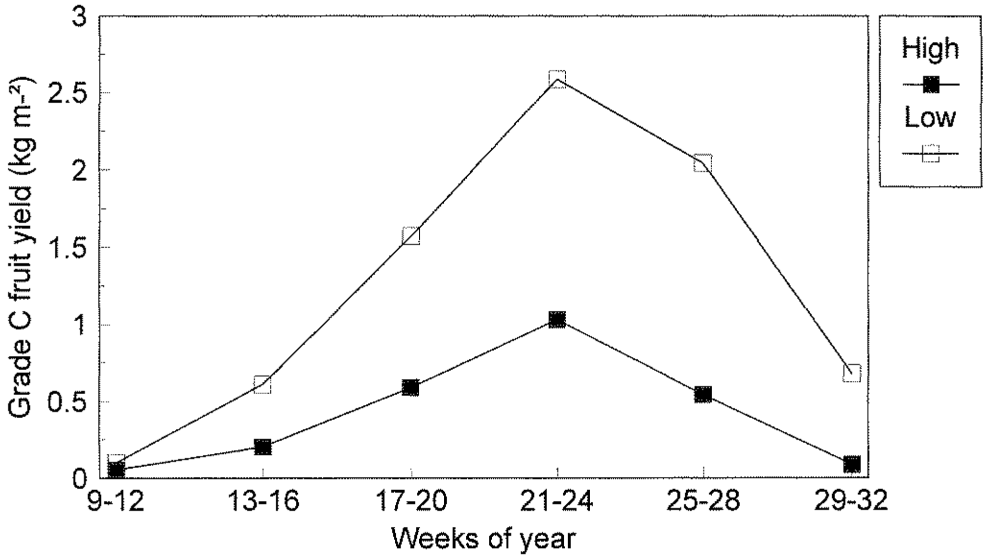


Fig. 30. The effects of time of taking side shoots on yield of Grade C fruit

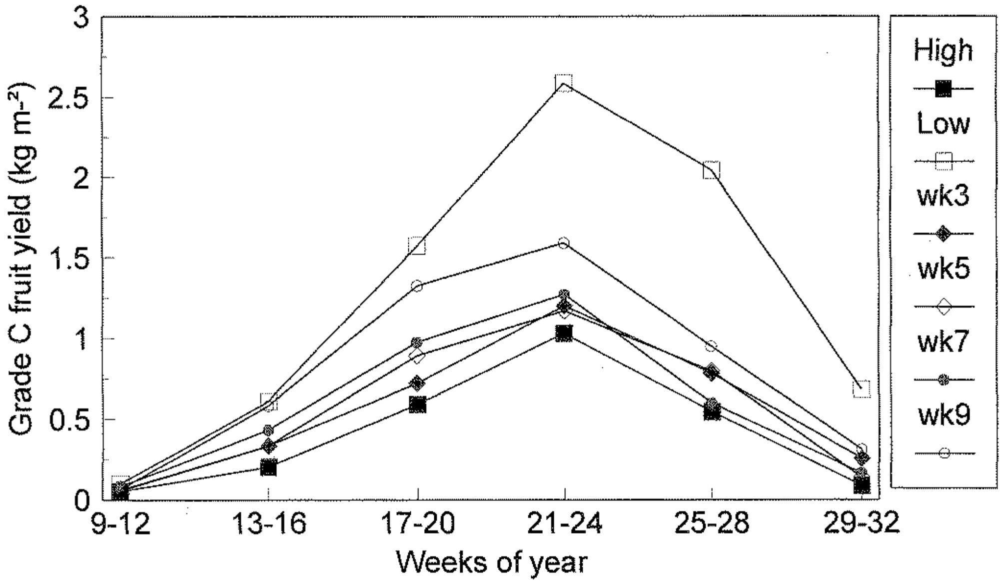


Fig. 31. The effects of initial planting density on the proportion of Class I fruit that are grade C

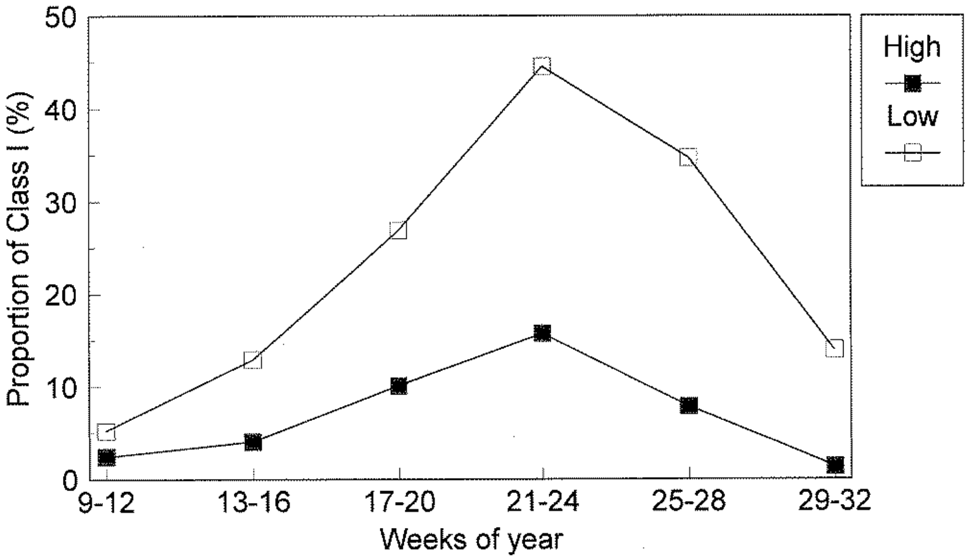


Fig. 32. The effects of time of taking side shoots on the proportion of Class I fruit that are grade C

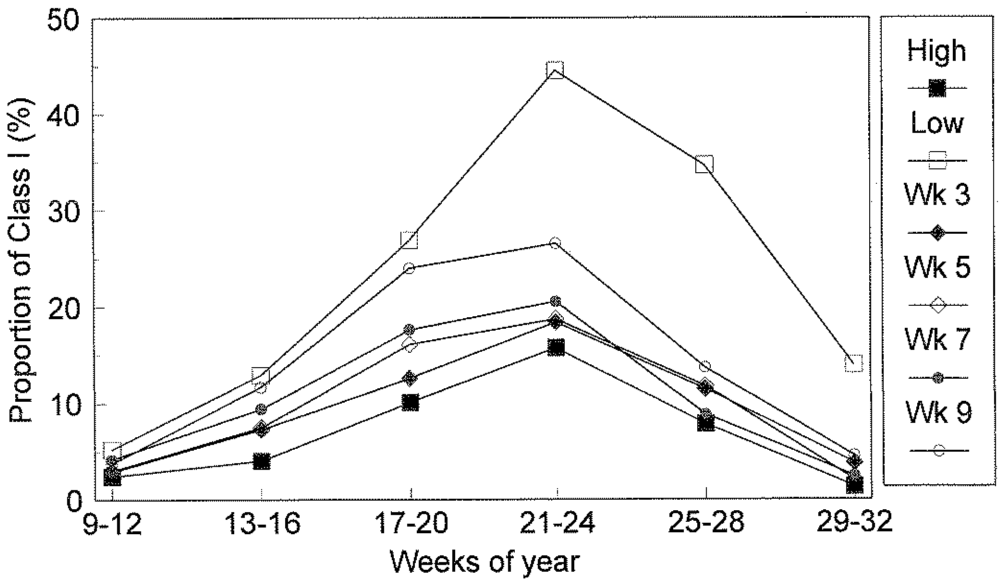


Fig. 33. The effects of initial planting density on yield of Grade E fruit

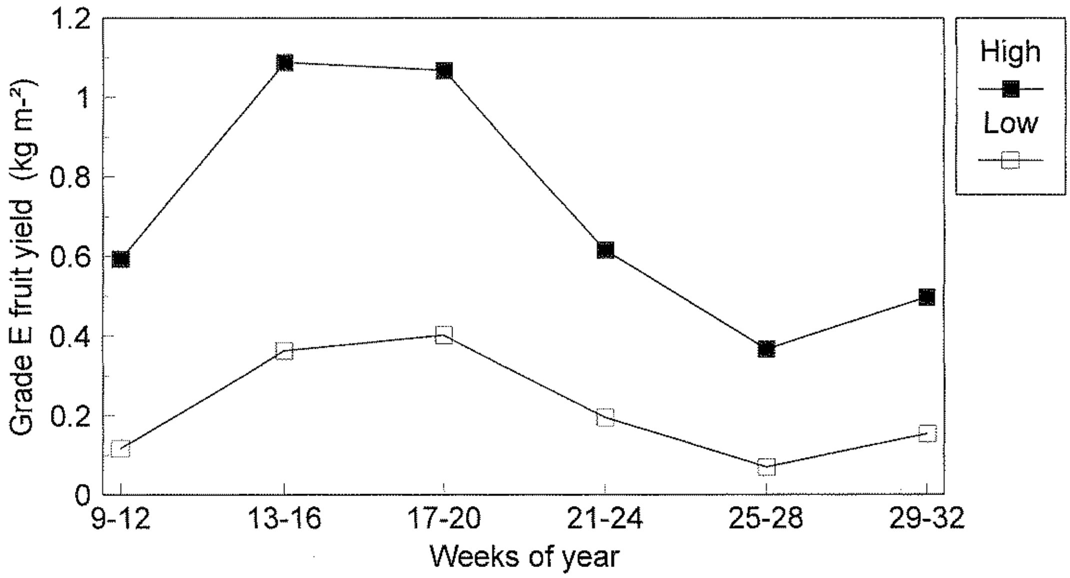


Fig. 34. The effects of time of taking side shoots on yield of Grade E fruit

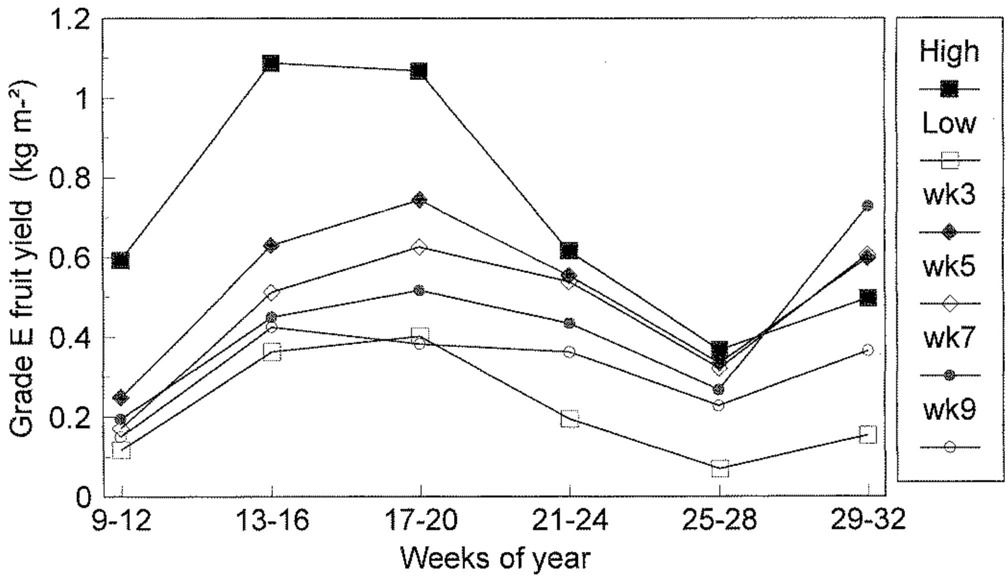


Fig. 35. The effects of initial planting density on the proportion of Class I fruit that are grade E

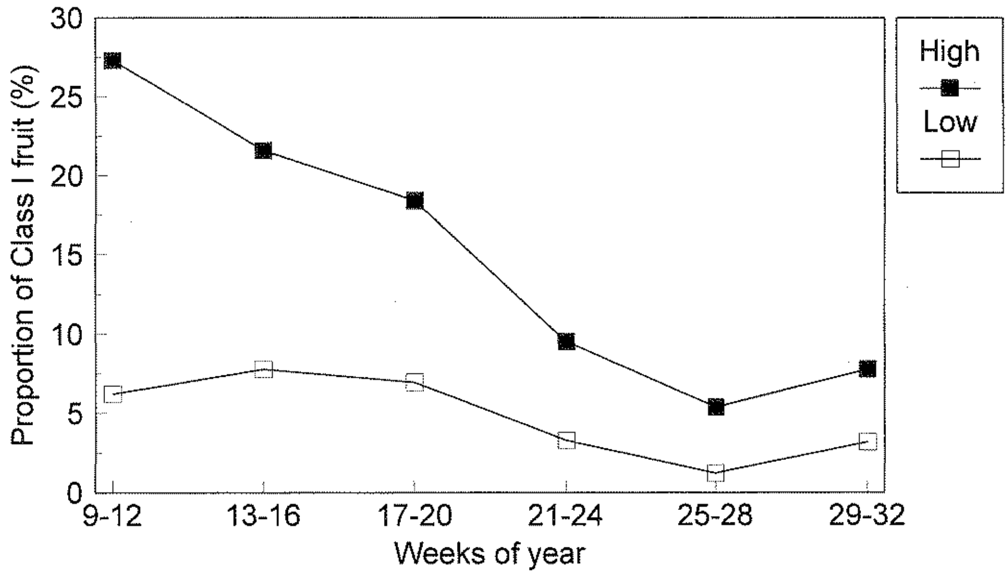
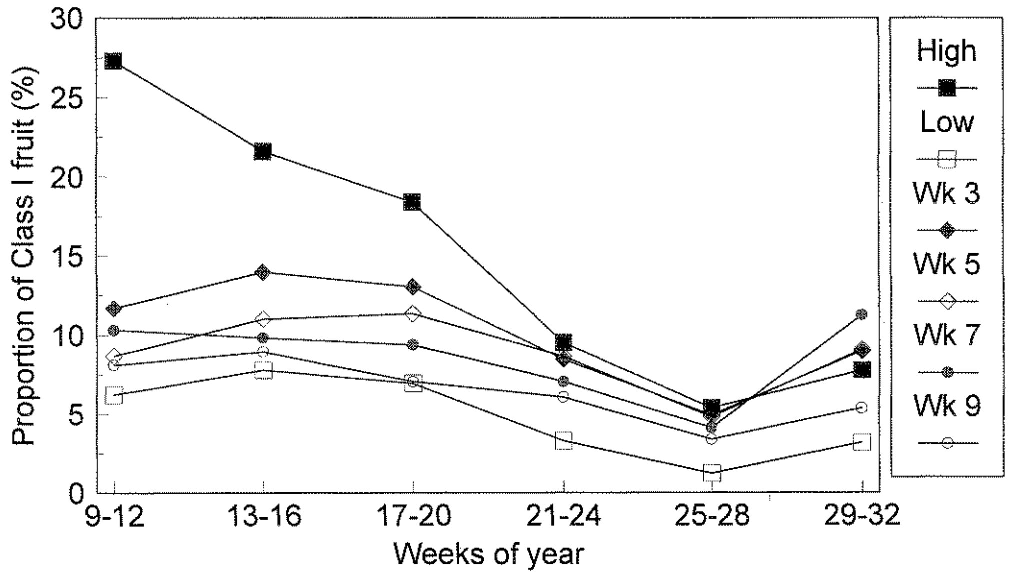


Fig. 36. The effects of time of taking side shoots on the proportion of Class I fruit that are grade E



CONCLUSIONS

1. Concepts

Although plant development is the outcome of complex interactions between many different plant processes and the environment in which the plant is growing, the results of the present experiment suggest that, for practical purposes, the processes regulating fruit size in tomato can be greatly simplified and are adequately described by the following concepts.

1.1. Firstly, every fruit has the potential to grow to any size from grade F to grade C but the size they actually achieve is dependent mainly on the amount of assimilate produced by the foliage and the number of fruit competing for the assimilate. In some circumstances, the availability of water for fruit growth should also be considered.

1.2. The amount of assimilate produced by the foliage is regulated by photosynthesis, which, in turn, is dependent on the quantity of solar radiation incident on the crop, the area of foliage available to intercept solar radiation, and the average CO_2 concentration by day. For convenience, canopy photosynthesis, solar radiation and leaf area should be expressed on a common basis, preferably as quantities relative to unit ground area of crop, e.g. per m^2.

1.3. The number of fruit competing for assimilate is related to the rate of production of fruit trusses per plant, the numbers of fruit set on each truss and, so that fruit number can also be expressed relative to unit ground area of crop, we need the number of plants per m^2. To complete the picture, it is also necessary to take note of the fact that fruit do not grow at the same rate throughout their life and so, not all fruit are growing equally rapidly at any moment in time.

2. Initial plant density

In terms of the above concepts, increasing initial plant density by 50% would be expected to increase the ratio of leaf area to ground area (i.e. leaf area index, LAI) by a similar proportion. This increase should allow the crop to intercept more light and thus to produce more assimilate and to increase fruit yield, although not necessarily in proportion to the increase in LAI. The yields of marketable fruit (Fig. 7 and Tables 1 and 2) showed that this benefit was gained both early in the cropping season and later, in weeks 29-32. Measurement made at the end of the crop's life indicated that, in addition to these simple effects of initial plant density on LAI, the leaves of plants at high density were actually 15% larger on average than those at low density: a response that should have further enhanced light interception in this treatment in summer. Leaf size in at least one of the side-shoot treatments (week 5) was also greater than in the low density control.

The main benefit of increasing initial plant density is to increase the number of fruit trusses produced per m^2 of ground area and thus the number of fruit per m^2 (Table 7). In the present experiment, however, the increase in fruit number was proportionally greater than the increase in yield (Table 1) and so mean fruit size was smaller at the higher density throughout the picking season (Table 10). Within Class I, the yield of grade D fruit was increased by the higher plant density from mid-season onwards (Fig. 21), while the yield of grade C fruit was reduced in mid-season (Fig. 29) and the yield of grade E fruit was greatly increased in the early part of the season (Fig. 33). Mean fruit weight reached a maximum value at about the time that the crop received its highest monthly total of solar radiation and then decreased as solar radiation levels declined (fig. 17).

3. Side shoots

The object of the present experiment was to plant at a low density and then, at different times, to add sufficient side shoots to increase the effective plant density to be equivalent to that of the high density control. These side shoots were also added in either two or four tranches spread over a period of up to six weeks, but the results showed that there was no significant benefit to be gained from adding side shoots in four tranches. The addition of side shoots created some competition for light and assimilates between the fruit-bearing main stem and the developing side shoot in the early stages of its growth. This competition did not appear to depress early yields from the main stem, even when side shoots were taken as early as week 3 (Table 1), although it did increase the early yield of grade E fruit (Table 21) and reduce mean fruit weight (Table 10). As the side shoots developed, however, they were expected to increase the LAI of the whole crop and so lead to increases in assimilate production and thus, marketable yield as well as increasing the numbers of fruits per m^2 in line with changes in incident solar radiation.

In the week 3 treatment, the first side shoots were taken in week 3 and the first fruit were picked from them in week 15, i.e. about 88 days later. The last side shoots of this treatment were taken in week 9 (four times of taking, each two weeks apart) and their first fruit were picked in week 20, i.e. about 81 days later. The first noticeable response to taking side shoots in the week 3 treatment was a significant reduction in mean fruit weight from weeks 13-16 onwards (Table 10): this occurred before any significant number of fruit had been picked from the side shoot and was, therefore, probably due to competition between the main shoot and the side shoot. Another early response was a significant increase in the number of fruit picked from weeks 17-20 onwards (Table 7). Marketable yield first began to increase from weeks 21-24 onwards (Table 1). In the week 7 treatment, the side shoots were taken four weeks later and, while the patterns of change were similar to those in the week 3 treatment, they were generally offset by about four weeks. Thus, the oldest side shoots of this treatment produced marketable fruit in week 19 while the youngest probably did so in about weeks 24 or 25; mean fruit weight fell from weeks 17-20 onwards; the number of fruit picked increased from weeks 21-24 onwards, and marketable fruit yield increased from weeks 25-28 onwards. The week 5 and week 9 treatments also showed similar effects and, together with the week 3 and week 7 treatments, produced linearly graded responses from the week 3 to the week 9 treatment. These linear trends are particularly evident in the effects of treatment on mean fruit weight (Table 10) and on mean fruit weight relative to that in the low density control.

One further effect of taking side shoots was to reduce the variation in mean fruit weight through the season. The smallest variation in mean fruit weight per month was obtained in the week 5 treatment, ranging from 67.21 g per fruit in weeks 9-12 to 77.01 g per fruit in weeks 25-28, a spread of only 9.8 g. At low density, the range was from 68.41 to 90.57 g per fruit, a spread of 22.16 g. In general, increasing fruit number per m^2 by means of taking side shoots reduced the weight of grade C fruit but increased the weight of grade E fruit and greatly increased that of grade D fruit relative to the low density control. A particular benefit of planting at low density and then adding side shoots was that the proportion of Class I fruit that were grade D was raised to over 85% in the first four weeks of picking, whereas in the high density control it was less than 70% in the same period (Table 13).

4. Practical considerations

The results demonstrated that there were benefits to be gained from planting at a low density and then increasing the effective plant density by taking side shoots, especially when these started to be taken as early as weeks 3 or 5. One advantage is that fewer plants have to be purchased per cropped acre and the other principal advantage is that the technique allows fruit numbers per m^2 to increase in line with increases in solar radiation incident per m^2. As a result, mean fruit weight is more uniform throughout the cropping season. There did not appear to be any particular advantage to be gained from taking the required number of side shoots in four tranches rather than two.

If the general concepts that have already been outlined are correct, then the optimum plant density for a given fruit size will depend upon characteristics of the cultivar, notably its ability to produce assimilate, the number of fruit it carries on each truss and the rate at which it produces trusses. Assimilate production will also depend on the average quantity of solar radiation incident at the glasshouse location, the light transmission of the glasshouse, and the average CO_2 concentration to be employed, especially in summer. These considerations suggest that higher final plant densities would be required in modern glasshouses, at more southern locations, and with higher average CO_2 concentrations. Sowing date is another factor; higher densities being required at later sowing dates. The use of higher air temperatures will increase the rate of truss production and shorten the growth period of fruits, and so will tend to reduce fruit size. Indeed, changes in CO_2 concentration and temperature might be considered as means of changing fruit size in the short term as could changes in the conductivity of the nutrient solution which would affect the availability of water for fruit growth.

5. The future

A number of relevant questions remain to be answered. First, since it is beneficial to increase the number of fruit harvested per m^2 in the period up to July, it might also be beneficial to reduce them again as the average quantity of solar radiation incident on the crop declines through autumn. In this respect, suitable allowance must be made for reducing average temperatures in autumn, which will slow both fruit development and truss formation. Allowance must also be made for the practice of "stopping" crops towards the end of the season for this reduces the number of fruit competing for assimilates and reduces competition from developing vegetative organs. Both of these factors will tend to increase mean fruit weight. Finally, further experimentation is required to resolve whether taking all of the required side shoots in only one tranche is detrimental; whether there are further benefits to be gained from extending the period over which side shoots are taken, and whether the number of side shoots that are taken and thus the final effective plant density should be increased yet further for a short time so as to reduce mean fruit size in weeks 21 to 28.

Appendix 1

Diary of events

Week No.	Week begin		Day of Expt.	Side shoot taken	First pick
1	Jan.	4	60		
2		11	67		
3		18	74	Week 3: taken from below truss 4	
4		25	81		
5	Feb.	1	88	Week 5: taken from below truss 6	
6		8	95		
7		15	102	Week 7: taken from below truss 8	
8		22	109		
9	Mar.	1	116	Week 9: taken from below truss 10	Main (Day 118)
10		8	123		
11		15	130	Week 11: taken from below truss 12	
12		22	137		
13		29	144	Week 13: taken from below truss 14	
14	Apr.	5	151		
15		12	158	Week 15: taken from below truss 16	Week 3 (Day 162)
16		19	165		
17		26	172		Week 5 (Day 174)
18	May	3	179		
19		10	186		Week 7 (Day 186)
20		17	193		Week 9 (Day 197)
21		24	200		
22		31	207		
23	June	7	214		
24		14	221		
25		21	228		
26		28	235		
27	July	5	242		
28		12	249		
29		19	256		
30		26	263		
31	Aug.	2	270		
32		9	277	Crop records ended	

Appendix 2

Table 1. Marketable fruit picked per four weeks (kg m-2)

Weeks of Year	High density	Treatments: Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	2.220	2.182	2.015	1.980	1.909	1.931	Hi, - , Lin
13-16	5.371	4.899	4.930	4.844	5.168	5.028	Hi, - , -
17-20	6.018	5.992	5.876	5.951	6.032	6.155	ns
21-24	6.999	7.069	6.768	6.603	6.818	6.710	ns
25-28	7.595	7.441	7.337	7.309	7.913	6.915	ns
29-32	7.310	7.507	7.454	7.339	8.193	6.202	- , Lo, Lin

Table 2. Cumulative total of marketable fruit (kg m-2)

Weeks of Year	High density	Treatments: Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	2.220	2.182	2.015	1.980	1.909	1.931	Hi, - , Lin
9-16	7.591	7.081	6.945	6.824	7.077	6.959	Hi, - , -
9-20	13.609	13.073	12.821	12.775	13.109	13.114	ns
9-24	20.608	20.142	19.589	19.378	19.927	19.824	ns
9-28	28.203	27.583	26.926	26.687	27.840	26.739	ns
9-32	35.513	35.090	34.380	34.026	36.033	32.941	- , Lo , -

N.B. in all of the following Tables, the abbreviations in the 'Sig' column mean:-

Hi = The value for the high density control is significantly ($P < 0.05$) different from the average value of all of the side-shoot treatments and the low density control.

Lo = The value for the low density control is significantly ($P < 0.05$) different from the average value of all of the side-shoot treatments.

Lin = The means of the side shoot treatments form a linear series of increasing or decreasing values when ranked in order of time of starting to take side shoots, i.e. from week 3, through weeks 5 and 7, to week 9.

Table 3. Class I fruit picked per four weeks (kg m-2)

Weeks of Year	High density	Treatments: Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	2.174	2.140	1.973	1.948	1.871	1.889	Hi, - , Lin
13-16	5.043	4.591	4.687	4.582	4.822	4.683	ns
17-20	5.805	5.702	5.515	5.518	5.452	5.801	ns
21-24	6.495	6.548	6.245	6.167	5.967	5.850	- , - , Lin
25-28	6.890	6.790	6.707	6.552	6.918	5.834	- , Lo, -
29-32	6.400	6.664	6.686	6.484	6.845	4.841	- , Lo, -

Table 4. Cumulative total of Class I fruit (kg m-2)

Weeks of Year	High density	Treatments: Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	2.174	2.140	1.973	1.948	1.871	1.889	Hi, - , Lin
9-16	7.217	6.731	6.660	6.530	6.693	6.572	Hi, - , -
9-20	13.022	12.433	12.175	12.048	12.145	12.373	Hi, - , -
9-24	19.517	18.981	18.420	18.215	18.112	18.223	Hi, - , Lin
9-28	26.407	25.771	25.127	24.767	25.030	24.057	ns
9-32	32.807	32.435	31.813	31.251	31.875	28.898	- , Lo, Lin
% Market	92.38	92.43	92.53	91.84	88.46	87.73	

Table 5. Class II fruit picked per four weeks (kg m-2)

Weeks of Year	High density	wk3	wk5	wk7	wk9	Low density	Sig
		Treatments					
		Time of starting to take side shoots					
9-12	0.046	0.042	0.042	0.032	0.038	0.042	ns
13-16	0.328	0.308	0.243	0.262	0.346	0.345	ns
17-20	0.213	0.290	0.361	0.433	0.580	0.354	-, - , Lin
21-24	0.504	0.521	0.523	0.436	0.851	0.860	-, - , Lin
25-28	0.705	0.651	0.630	0.757	0.995	1.081	- , Lo, Lin
29-32	0.910	0.843	0.768	0.855	1.348	1.361	- , Lo, Lin

Table 6. Cumulative total of Class II fruit (kg m-2)

Weeks of Year	High density	wk3	wk5	wk7	wk9	Low density	Sig
		Treatments					
		Time of starting to take side shoots					
9-12	0.046	0.042	0.042	0.032	0.038	0.042	ns
9-16	0.374	0.350	0.285	0.294	0.384	0.387	ns
9-20	0.587	0.640	0.646	0.727	0.964	0.741	-, - , Lin
9-24	1.091	1.161	1.169	1.163	1.815	1.601	-, - , Lin
9-28	1.796	1.812	1.799	1.920	2.810	2.682	-, - , Lin
9-32	2.706	2.655	2.567	2.775	4.158	4.043	- , Lo, Lin

Table 7. Numbers of marketable fruit picked per m2 per 4 weeks

Weeks of Year	High density	wk3	wk5	wk7	wk9	Low density	Sig
	Treatments						
		Time of starting to take side shoots					
9-12	38.96	33.46	29.92	29.63	28.23	28.17	Hi, - , Lin
13-16	91.92	75.79	73.73	70.85	73.06	71.33	Hi, - ,
17-20	94.29	86.81	81.83	80.29	78.63	79.75	Hi, - , Lin
21-24	95.08	94.17	89.50	85.13	84.56	76.17	Hi, Lo, Lin
25-28	99.70	99.40	95.20	95.00	98.00	75.80	- , Lo, -
29-32	104.00	106.00	106.30	104.00	110.40	76.50	- , Lo, -
9-32	523.95	495.63	476.48	464.9	472.88	407.72	

Table 8. Numbers of marketable fruit picked per m2 per 4 weeks

Weeks of Year	High density	Low density	Ratio of High to Low
	Treatments		
9-12	38.96	28.17	1.38
13-16	91.92	71.33	1.29
17-20	94.29	79.75	1.18
21-24	95.08	76.17	1.25
25-28	99.70	75.80	1.32
29-32	104.00	76.50	1.36
9-32	523.95	407.72	1.29
Per plant	171.45	200.16	0.86

Table 9. Numbers of Class I fruit picked per m2 per four weeks

Weeks of Year	High density 12k	Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density 8k	Sig
9-12	38.21	32.85	29.39	29.19	27.73	27.63	Hi, - , Lin
13-16	85.04	69.94	69.31	66.56	67.73	65.33	Hi, - , -
17-20	89.71	81.62	75.79	73.54	70.06	73.79	Hi, - , Lin
21-24	88.21	87.17	82.44	76.84	73.96	65.92	Hi, Lo, Lin
25-28	90.67	88.48	87.04	84.39	86.17	64.34	- , Lo, -
29-32	91.63	94.67	95.64	91.54	93.33	60.04	- , Lo, -
9-32	483.47	454.73	439.61	422.06	418.98	357.05	

Table 10. Mean fruit weight (g per Class I fruit)

Weeks of Year	High density	Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	56.89	65.17	67.21	66.69	67.47	68.41	Hi, - , -
13-16	59.30	65.54	67.58	68.84	71.09	71.70	Hi, Lo, Lin
17-20	64.72	69.91	72.80	75.08	77.81	78.57	Hi, Lo, Lin
21-24	73.68	75.16	75.80	77.82	80.83	89.05	Hi, Lo, Lin
25-28	75.96	76.74	77.01	76.72	80.25	90.57	Hi, Lo, Lin
29-32	69.88	70.38	69.92	69.21	73.35	80.64	- , Lo, -

Table 11. Grade D fruit picked per four weeks (kg m-2)

Weeks of Year	High density	Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	1.502	1.822	1.743	1.666	1.648	1.668	Hi, - , Lin
13-16	3.697	3.590	3.772	3.649	3.785	3.668	ns
17-20	4.043	4.187	3.956	3.997	3.707	3.790	- , - , Lin
21-24	4.976	4.747	4.495	4.426	3.993	3.041	Hi, Lo, Lin
25-28	5.978	5.669	5.584	5.686	5.739	3.718	- , Lo, -
29-32	5.814	5.807	5.942	5.591	6.168	4.008	- , Lo, -

Table 12. Cumulative total of Grade D fruit (kg m-2)

Weeks of Year	High density	Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	1.502	1.822	1.743	1.666	1.648	1.668	Hi, - , Lin
9-16	5.199	5.412	5.515	5.315	5.433	5.336	ns
9-20	9.242	9.599	9.471	9.312	9.140	9.126	ns
9-24	14.218	14.346	13.966	13.738	13.133	12.167	- , Lo, Lin
9-28	20.196	20.015	19.550	19.424	18.872	15.885	Hi, Lo, Lin
9-32	26.010	25.822	25.492	25.015	25.040	19.893	-, Lo, -

Table 13. Proportion of Class I fruit that are grade D (%)

Weeks of Year	High density	Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	69.10	85.05	88.25	85.34	87.84	88.35	Hi, - , -
13-16	73.27	77.95	80.49	79.65	78.74	78.42	Hi, - , -
17-20	69.68	73.48	71.74	72.44	68.18	65.45	ns
21-24	73.91	72.44	71.97	71.84	66.99	51.71	- , Lo, -
25-28	86.77	83.54	83.31	86.97	82.89	64.06	- , Lo, -
29-32	90.84	87.16	88.86	86.30	90.09	82.89	- , Lo, -
9-32	79.28	79.61	80.13	80.05	78.56	68.84	- , Lo, -

Table 14. Grade DL fruit picked per four weeks (kg m-2)

Weeks of Year	High density	wk3	wk5	wk7	wk9	Low density	Sig
		Treatments: Time of starting to take side shoots					
9-12	0.634	1.137	1.131	1.047	1.087	1.097	Hi, - , -
13-16	1.746	2.272	2.551	2.531	2.793	2.744	Hi, - , Lin
17-20	2.417	2.839	2.890	3.055	2.903	2.936	Hi, - , -
21-24	3.502	3.497	3.266	3.397	3.199	2.556	- , Lo, -
25-28	4.462	4.160	4.082	4.168	4.560	3.343	- , Lo, -
29-32	3.309	3.399	3.365	3.112	4.077	3.180	- , - , Lin

Table 15. Cumulative total of Grade DL fruit (kg m-2)

Weeks of Year	High density	wk3	wk5	wk7	wk9	Low density	Sig
		Treatments: Time of starting to take side shoots					
9-12	0.634	1.137	1.131	1.047	1.087	1.097	Hi, - , -
9-16	2.380	3.409	3.682	3.578	3.880	3.841	Hi, - , -
9-20	4.797	6.248	6.572	6.633	6.783	6.777	Hi, - , Lin
9-24	8.299	9.745	9.838	10.030	9.982	9.333	Hi, Lo, -
9-28	12.761	13.905	13.920	14.198	14.542	12.676	Hi, Lo, -
9-32	16.070	17.304	17.285	17.310	18.619	15.856	Hi, Lo, Lin

Table 16. Grade DS fruit picked per four weeks (kg m-2)

Treatments

Time of starting to take side shoots

Weeks of Year	High density	wk3	wk5	wk7	wk9	Low density	Sig
9-12	0.868	0.685	0.612	0.619	0.561	0.571	Hi, - , Lin
13-16	1.951	1.317	1.221	1.118	0.992	0.924	Hi, Lo, Lin
17-20	1.627	1.348	1.066	0.942	0.804	0.854	Hi, - , Lin
21-24	1.294	1.250	1.229	1.028	0.794	0.485	Hi, Lo, Lin
25-28	1.516	1.509	1.502	1.517	1.179	0.375	Hi, Lo, Lin
29-32	2.505	2.408	2.577	2.479	2.090	0.829	- , Lo, Lin

Table 17. Cumulative total of Grade DS fruit (kg m-2)

Treatments

Time of starting to take side shoots

Weeks of Year	High density	wk3	wk5	wk7	wk9	Low density	Sig
9-12	0.868	0.685	0.612	0.619	0.561	0.571	Hi, - , Lin
9-16	2.819	2.002	1.833	1.737	1.553	1.495	Hi, Lo, Lin
9-20	4.446	3.350	2.899	2.679	2.357	2.349	Hi, Lo, Lin
9-24	5.740	4.600	4.128	3.707	3.151	2.834	Hi, Lo, Lin
9-28	7.256	6.109	5.630	5.224	4.330	3.209	Hi, Lo, Lin
9-32	9.761	8.517	8.207	7.703	6.420	4.038	Hi, Lo, Lin

Table 18. Grade C fruit picked per four weeks (kg m-2)

Weeks of Year	High density	wk3	wk5	wk7	wk9	Low density	Sig
		Treatments					
		Time of starting to take side shoots					
9-12	0.053	0.061	0.058	0.084	0.068	0.100	ns
13-16	0.203	0.335	0.335	0.433	0.582	0.610	- , - , Lin
17-20	0.590	0.721	0.891	0.974	1.324	1.571	- , Lo, Lin
21-24	1.030	1.200	1.169	1.271	1.590	2.586	- , Lo, -
25-28	0.544	0.783	0.796	0.596	0.948	2.044	- , Lo, -
29-32	0.086	0.255	0.138	0.165	0.310	0.680	- , Lo, -

Table 19. Cumulative total of Grade C fruit (kg m-2)

Weeks of Year	High density	wk3	wk5	wk7	wk9	Low density	Sig
		Treatments					
		Time of starting to take side shoots					
9-12	0.053	0.061	0.058	0.084	0.068	0.100	ns
9-16	0.256	0.396	0.393	0.517	0.650	0.710	ns
9-20	0.846	1.117	1.284	1.491	1.974	2.281	- , Lo, Lin
9-24	1.876	2.317	2.453	2.762	3.564	4.867	Hi, Lo, Lin
9-28	2.420	3.100	3.249	3.358	4.512	6.911	Hi, Lo, Lin
9-32	2.506	3.355	3.387	3.523	4.822	7.591	Hi, Lo, -

Table 20. Proportion of Class I fruit that are grade C (%)

Weeks of Year	High density	wk3	wk5	wk7	wk9	Low density	Sig
		Treatments					
		Time of starting to take side shoots					
9-12	2.43	2.92	2.99	4.19	3.75	5.21	ns
13-16	4.03	7.28	7.48	9.42	11.68	12.91	Hi, - , -
17-20	10.10	12.60	16.10	17.60	24.00	26.90	Hi, Lo, Lin
21-24	15.74	18.38	18.72	20.52	26.57	44.54	Hi, Lo, Lin
25-28	7.84	11.47	11.79	8.84	13.68	34.69	Hi, Lo, -
29-32	1.35	3.80	2.06	2.45	4.54	13.94	- , Lo, -
9-32	7.64	10.34	10.65	11.27	15.13	26.27	Hi, Lo, Lin

Table 21. Grade E fruit picked per four weeks (kg m-2)

Weeks of Year	High density	Treatments: Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	0.593	0.249	0.171	0.195	0.150	0.117	Hi, Lo, Lin
13-16	1.088	0.630	0.512	0.450	0.425	0.363	Hi, Lo, Lin
17-20	1.068	0.744	0.626	0.517	0.383	0.402	Hi, Lo, Lin
21-24	0.616	0.554	0.539	0.434	0.362	0.195	Hi, Lo, Lin
25-28	0.367	0.334	0.321	0.267	0.227	0.069	- , Lo, Lin
29-32	0.497	0.598	0.606	0.727	0.365	0.153	- , Lo, Lin

Table 22. Cumulative total of Grade E fruit (kg m-2)

Weeks of Year	High density	Treatments: Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	0.593	0.249	0.171	0.195	0.150	0.117	Hi, Lo, Lin
9-16	1.681	0.879	0.683	0.645	0.575	0.480	Hi, Lo, Lin
9-20	2.749	1.623	1.309	1.162	0.958	0.882	Hi, Lo, Lin
9-24	3.365	2.177	1.848	1.596	1.320	1.077	Hi, Lo, Lin
9-28	3.732	2.511	2.169	1.863	1.547	1.146	Hi, Lo, Lin
9-32	4.229	3.109	2.775	2.590	1.912	1.299	Hi, Lo, Lin

Table 23. Proportion of Class I fruit that are grade E (%)

Weeks of Year	High density	Treatments: Time of starting to take side shoots wk3	wk5	wk7	wk9	Low density	Sig
9-12	27.30	11.68	8.68	10.31	8.11	6.22	Hi, - , -
13-16	21.59	13.97	11.00	9.82	8.94	7.78	Hi, Lo, Lin
17-20	18.41	13.04	11.34	9.38	7.06	6.95	Hi, Lo, Lin
21-24	9.52	8.47	8.64	7.05	6.08	3.29	Hi, Lo, Lin
25-28	5.37	4.93	4.81	4.13	3.38	1.21	- , Lo, Lin
29-32	7.76	8.97	9.07	11.24	5.36	3.17	- , Lo, Lin
9-32	12.89	9.59	8.72	8.29	6.00	4.50	Hi, Lo, Lin