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HDC Contract PC/65

REGULATION OF TOMATO FRUIT SIZE BY PLANT DENSITY AND TRUSS THINNING

Final Report

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REGULATION OF TOMATO FRUIT SIZE BY PLANT DENSITY AND TRUSS THINNING

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REGULATION OF TOMATO FRUIT SIZE BY PLANT DENSITY AND TRUSS THINNING

Relevance to growers and practical application

Application

As market outlets seem to 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. Removing some distal fruit from early trusses (truss thinning) will reduce the weight of small fruit produced in the early part of the season, while planting at a lower density than normal and then taking side shoots will reduce the initial cost of planting and can reduce the yield of large fruit produced in summer. Stopping plants at the end of the season will also reduce the production of small fruit and may improve fruit quality.

Summary

The market prefers Class I fruit in the D size grade but, when a long-season tomato crop is grown at one plant density throughout its life it is likely to produce too many small fruit in the early part of the season and too many large fruit in summer. 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.

The present work was undertaken 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 different densities, by taking side shoots, and by truss thinning.

The crop was 'Liberto', sown on 6 November and grown in NFT at the equivalent of either 8250 plants per acre (low density) or 12 376 plants per acre (high density). Side shoots were taken on 26 February and 30 March to add the equivalent of a total of 4126 heads per acre to each of the original plant densities. In the truss thinning treatment, 30% of the available fruit were removed from the end of each of the first three trusses. All stems were "stopped" on 21 September, two weeks before the final pick.

Planting at the higher plant density increased the overall yield of marketable and Class I fruit but reduced mean fruit size. In particular, the yield of E grade fruit was increased and the yield of C grade fruit was decreased in the early part of the season. The yield of D grade fruit was increased, however, mainly from mid-season onwards.

Taking side shoots tended to depress yield in the first 12 weeks of production, especially at the higher plant density, but treatment increased marketable and Class I yields once the side

shoots came into fruit production; about 70 to 75 days after the side shoots were taken. Once this stage had been reached, the two crops at the same effective plant density, i.e. low density plus side shoots, and high density without side shoots, produced similar fruit yields of similar mean fruit size. Overall, the taking of side shoots increased the yield of small fruit at the high density, reduced the yield of large fruit at the low density, and increased the yield of D grade fruit but only at the low density.

Truss thinning reduced the yield of small fruit produced by the treated trusses but also reduced their overall production of Class I fruit. This loss was recovered, however, as a result of increased production from those trusses immediately above the thinned ones.

The dry matter, sugar, and acid contents of D grade fruits were unaffected by any of the treatments, though the dry matter content increased with increasing incident solar radiation and appeared to be increased by "stopping". "Stopping" also increased mean fruit weight in the last month of harvest.

The results suggest that all three techniques could be used by growers to improve the uniformity of fruit size but also suggest that the techniques should be used with caution until growers have more experience with them and the results of further experiments are available. This work has also drawn attention to the need to consider other aspects, such as cultivar, the location and light transmission of the glasshouse, the average CO_2 concentration that can be maintained in summer, and the sowing date employed. Further work is needed to refine the procedure for truss thinning, and to define the optimum plant density, the best time to take sideshoots and whether to stagger the times of taking them. All of these aspects need to be related to incident solar radiation and to average CO_2 concentrations.

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. The market prefers Class I fruit in the D size grade, i.e. 47-57 mm in diameter; 50-90g fresh weight, and so, the present work was undertaken to see whether it was possible to produce a high proportion of fruit in the preferred size grade, all through the year.

There is good evidence to show that assimilate production varies in relation to incident solar radiation throughout the year while the proportion of the assimilate distributed to fruits remains relatively constant. 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. We attempted to do this either by increasing the effective plant density by taking side shoots as light levels increased, or by reducing the number of fruit per truss (i.e. truss thinning) on the first three trusses, when light levels were low. The effects of taking side shoots and of truss thinning were assessed on two different initial plant densities and, as controls, plants were grown at both initial densities but without further treatment. Sugar content and acidity are also important in determining fruit quality and so these attributes were assessed on samples of D grade fruit taken from all treatments throughout the period of fruit production.

THE EXPERIMENT

1. The crop

Seed of 'Liberto' was sown on 6 November 1991, 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 18 December 1991 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 raised from an initial level of 5 mS cm^{-1} (at planting) to 9 mS cm^{-1} (13 January), then lowered again to 5 mS cm^{-1} (late February), and then to approximately 3 mS cm^{-1}, thereafter. 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 15 January.

2. The glasshouse and aerial environment

The experiment was conducted in an end compartment (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 an average of 1000 vpm CO_2 until 7 April. The average CO_2 concentration was then lowered gradually and, from 23 April to 30 September, was controlled at 425 vpm, regardless of ventilation; it was then increased to an average of 520 vpm through October.

3. The layout

The glasshouse 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 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 for one of the four treatment combinations of two initial densities with or without side-shoots. Within the house, the 12 plots were grouped into three blocks of position, each containing one replicate of the four main treatment combinations. For the truss thinning treatments, each double row was split into northern and southern halves, one of which was treated while the other was not.

4. The treatments

4.1 *Initial density*

The density treatments comprised different numbers of plants per double row. These numbers have then been 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*

Side-shoots were taken on two occasions. On 26 February (week 9), side shoots were appearing in the axils of leaves around truss 8 and six plants, equally spaced around each double row, were selected for treatment. On each chosen plant, the side shoot in the axil of the third leaf above truss 8 was retained while all other shoots were removed. A similar procedure was adopted on 30 March (week 14), when side shoots were appearing around truss 12. Six further plants, equally spaced between those that were treated earlier, were selected and the side shoot in the axil of the third leaf above truss 12 was retained. The final number of heads was:

Low density = (8k + ss)	24 plants + 12 side shoots per double row, equivalent to approximately 3.056 heads m^{-2} (12 376 heads per acre).
High density = (12k + ss)	36 plants + 12 side shoots per double row, equivalent to approximately 4.074 heads m^{-2} (16 501 heads per acre).

Fruit from the first side shoot were picked in the week beginning 11 May (week 20), indicating that side shoots began to contribute to fruit yield about 75 days after the shoots were selected at the end of February. Shoots taken on the second occasion produced fruit that began to be picked in the week beginning 8 June (week 24), about 70 days after selection of the side shoots on 30 March. A timetable of the principal events is given in Appendix 1.

4.3 *Truss thinning*

The average number of marketable fruit that were set on each of the first three trusses of the two initial planting densities was recorded when all fruit had been set (truss 1 on 23 January; truss 2 on 29 January, and truss 3 on 4 February). Immediately after recording, about 30% of the fruit were removed from the distal end of the appropriate trusses in the half plots assigned to the truss thinning treatment. Truss thinning, therefore, was performed about six weeks before the first fruits were picked from the treated trusses. The average number of fruit set and the number of fruit remaining per truss in the truss thinning treatment are shown in Table 1.

Table 1

		Number of fruit set	Number of fruit remaining
Truss 1	Low density	8.8	6
	High density	6.8	5
Truss 2	Low density	7.0	5
	High density	6.2	4
Truss 3	Low density	8.1	6
	High density	6.4	5
Total	Low density	23.9	17
	High density	20.4	14

At this stage, these numbers of fruit per plant represented fruit densities of 63.2 and 49.4 fruit m^{-2} in the high and low density treatments, respectively, without truss thinning, and 43.4 and 35.1 fruit m^{-2} in the same treatments but with truss thinning.

4.4 *"Stopping"*

The stems of each head were decapitated ("stopped") on 21 September (week 39) at a point three leaves above the truss that had most recently reached anthesis. The main stem was stopped above truss 36, on average, while the first batch of sideshoots was stopped above truss 26 and the second batch above truss 22, on average.

5. Records

5.1 *Fruit weight*

Fruit were normally picked from every half-plot on three occasions each week, starting from 2 March; 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 are presented in Appendices 2 and 4. Final fruit yields are presented in Appendix 3.

5.2 *Fruit numbers*

The numbers of fruit picked from every half-plot in each size category of Class I and in Class II and waste were counted on each harvest occasion. In addition, for the first eight weeks of picking, fruit picked from trusses 1, 2, and 3 were recorded separately from each other and from the remainder (i.e. truss 4 and above).

5.3 *Fruit quality*

Six D_L fruit were taken at intervals from each half-plot and cut into four quarters. Two quarters from each of the six fruit were weighed (fresh weight), dried in an oven at 80°C for three days and then weighed again (dry weight). Dry matter contents were then calculated as (dry weight ÷ fresh weight) x 100.

The other quarters were frozen until required for further analysis. They were then thawed overnight, pressed through tissue to liberate sap that was then centrifuged and filtered. Samples of the pressed sap were then taken to estimate refractive index (°Brix), sugar content and acidity. Brix was measured in a refractometer; sugar content was measured as glucose by an autoanalyser, and acid was measured as titratable acidity using 0.1N NaOH. Fruit assayed by the above methods were taken from trusses 1, 2, and 3, and then every two weeks from the fifth to the 23rd week of picking. Thereafter, samples were taken every four weeks.

The reasons for downgrading fruit to Class II were also recorded on occasions.

RESULTS

1. Solar radiation

The amount of solar radiation incident on the glasshouse in each successive four-week period increased steadily up to a maximum in weeks 22 to 25 (25 May to 21 June) from which it then generally declined (Fig. 1).

2. Effect of initial planting density

The yield of marketable fruit produced in each four-week period from the onset of picking (week 10) followed a similar trend to that of solar radiation but with a lag period of about four weeks for, at both densities, maximum production occurred in weeks 26 to 29 (22 June to 19 July) (Fig. 2). The higher density (12k) produced a significantly heavier yield of marketable fruit in almost all periods from week 22 onwards (Fig. 2).

The seasonal pattern of production of Class I fruit yield was slightly different from that for marketable yield; maximum production occurred four weeks earlier (weeks 22 to 25) at the higher density (12k) and eight weeks earlier (weeks 18 to 21) at the lower density (8k) (Fig. 3). The main reason for this being the increased production of Class II fruit between weeks 26 and 37 in the higher density treatment (Fig. 4). The final yield of marketable fruit was 13.2% greater at the higher density while that of Class I fruit was 16.5% greater (Fig. 5).

Overall, the 8k treatment produced 542 fruit m^{-2} while the 12k produced 727, an increase of about 34%. The increase in the number of plants was 50%, however, and so, on average, fewer fruit were set or were marketed from each truss at the higher plant density. Although the overall number of Class I fruit was increased by 38% (from 441 to 607 fruit m^{-2}) at the higher density, the increase in Class I yield was only 16.5% and so mean fruit weight was always about 10g heavier at the lower density (Fig. 6).

The number of Class I fruit picked in each successive four-week period followed a seasonal pattern in which it more than doubled between week 10 and week 21, but thereafter slowly declined (Fig. 7). The reasons for this decline in fruit number are not known. The decline might indicate that the number of fruit set per truss was reduced as the fruit 'load' per plant increased, although it occurred at the same time in both plant densities. Alternatively, it might reflect differences in the rate of fruit maturation as influenced by changes in average temperature. These changes in fruit number contributed to the monthly fluctuations in mean Class I fruit weight (Fig. 6). Mean fruit weight lessened from the onset of picking until weeks 18 to 21, as fruit number (Fig. 7) increased more rapidly than fruit yield (Fig. 2). In the next period (until weeks 26 to 29), mean fruit weight rose because fruit numbers fell while fruit yield was relatively stable, but thereafter, mean fruit weight fell again as both fruit number and fruit yield fell. In the very last month (weeks 38 to 41) mean fruit weight increased again, especially at the lower density. This probably occurred as a consequence of "stopping" in week 39 which stopped the further production of young leaves and stems and so, presumably allowed proportionally more assimilate to be available for fruit growth.

Fig. 1. The amount of solar radiation incident on the greenhouse

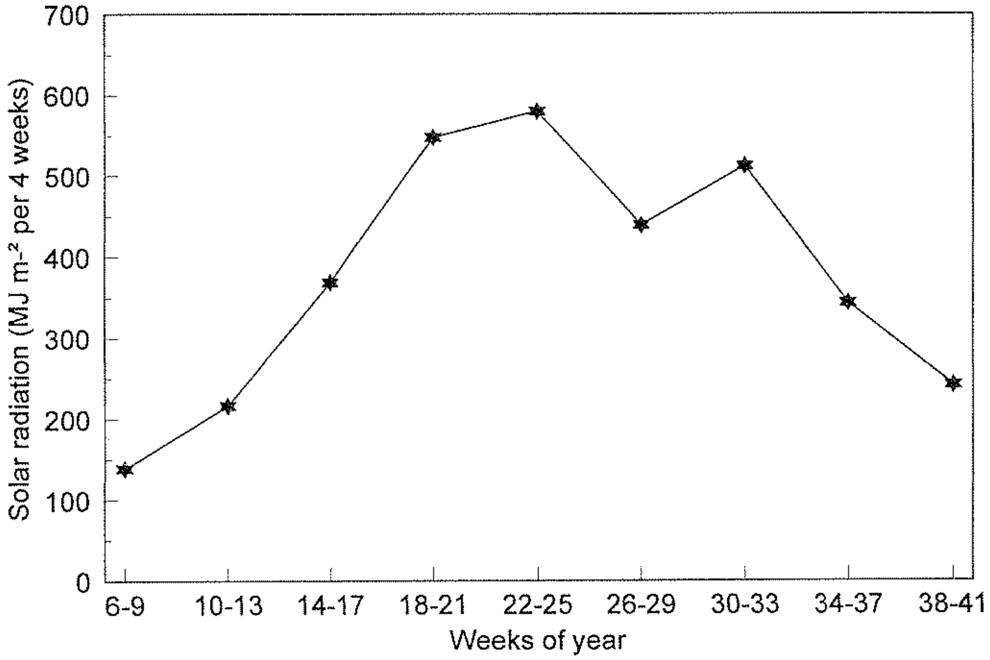


Fig. 2. The effects of crop density on yield of marketable fruit

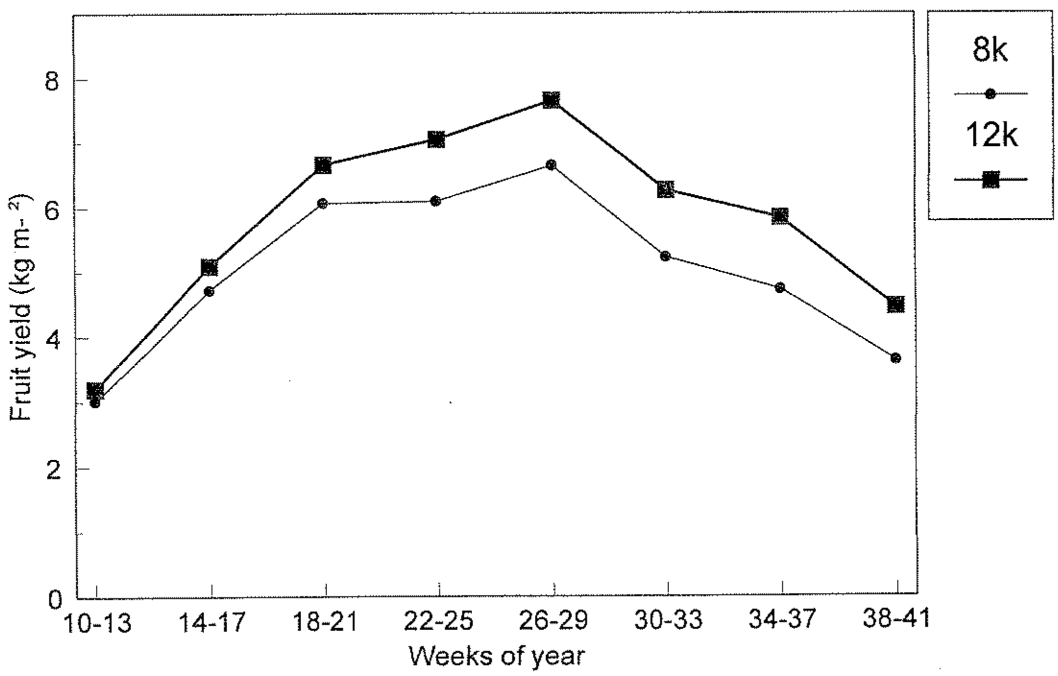


Fig. 3. The effects of crop density on yield of Class I fruit

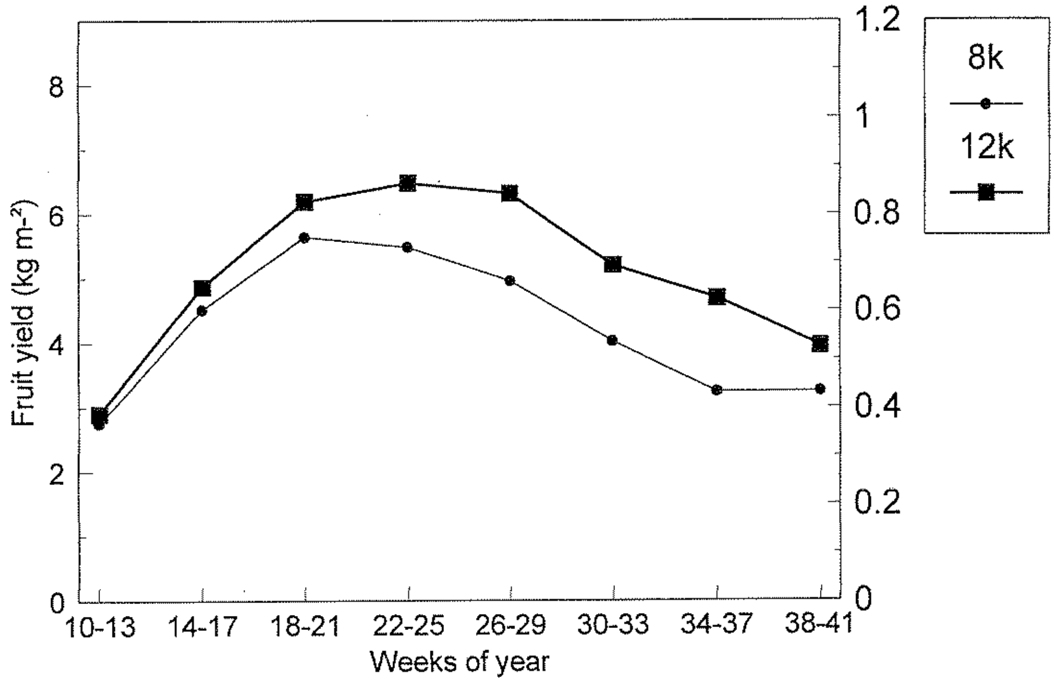


Fig. 4. The effects of crop density on yield of Class II fruit

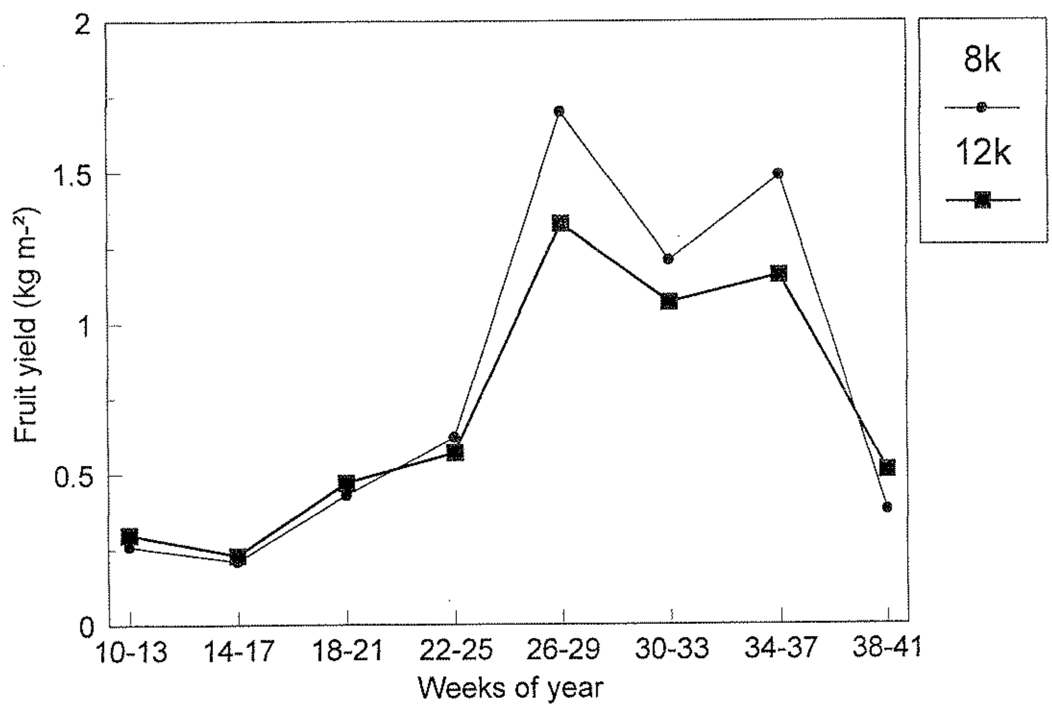


Fig. 5. The effects of crop density on final yields of marketable and Class I fruit

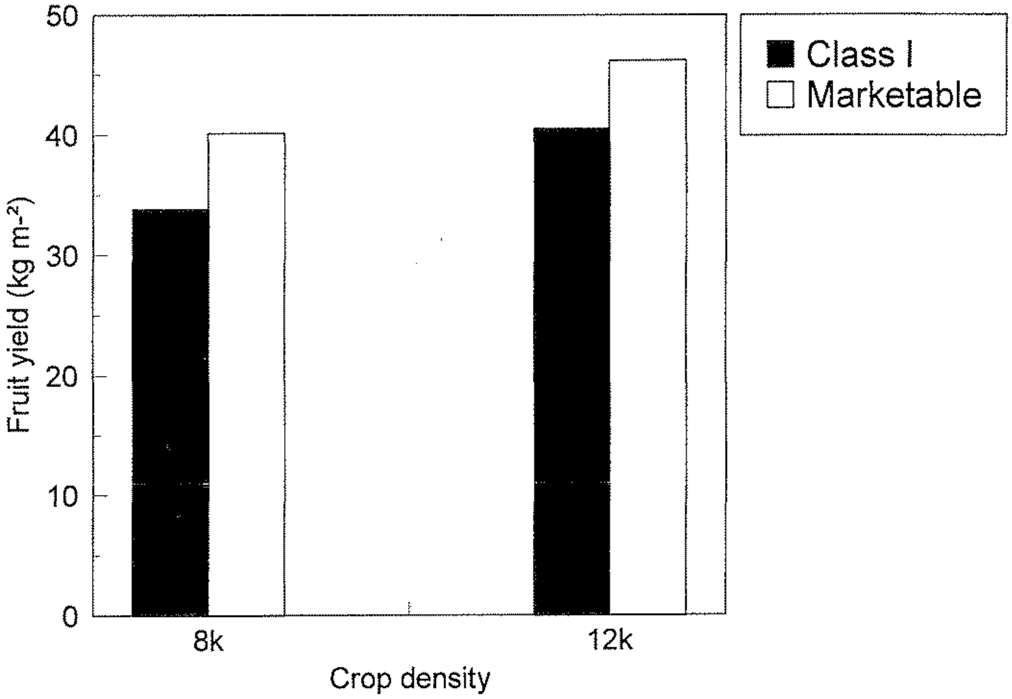


Fig. 6. The effects of crop density on mean fruit weight - Class I

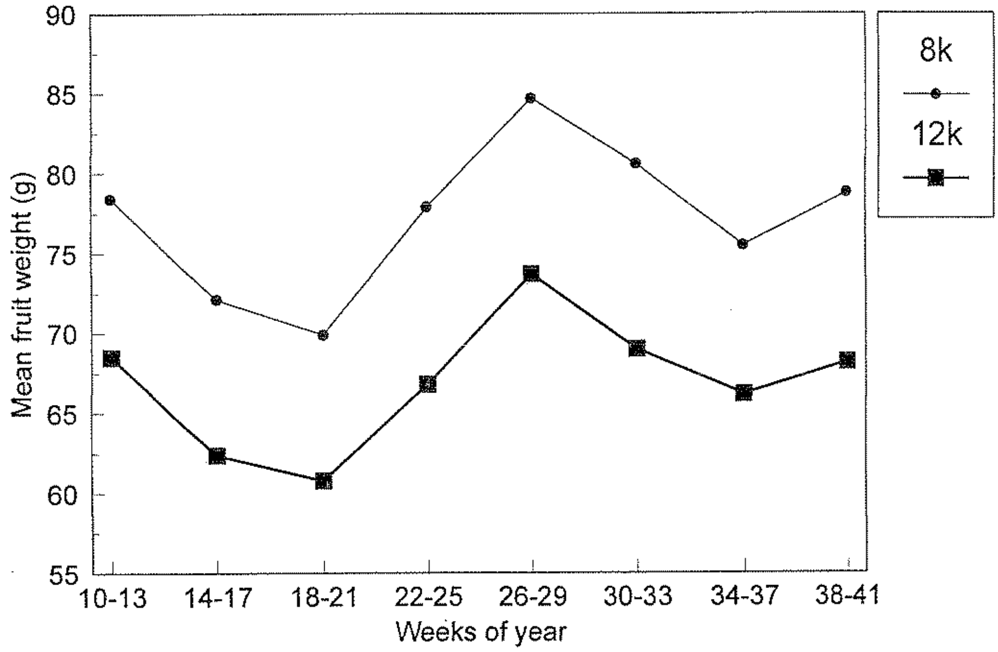


Fig. 7. The effects of crop density on average number of Class I fruit

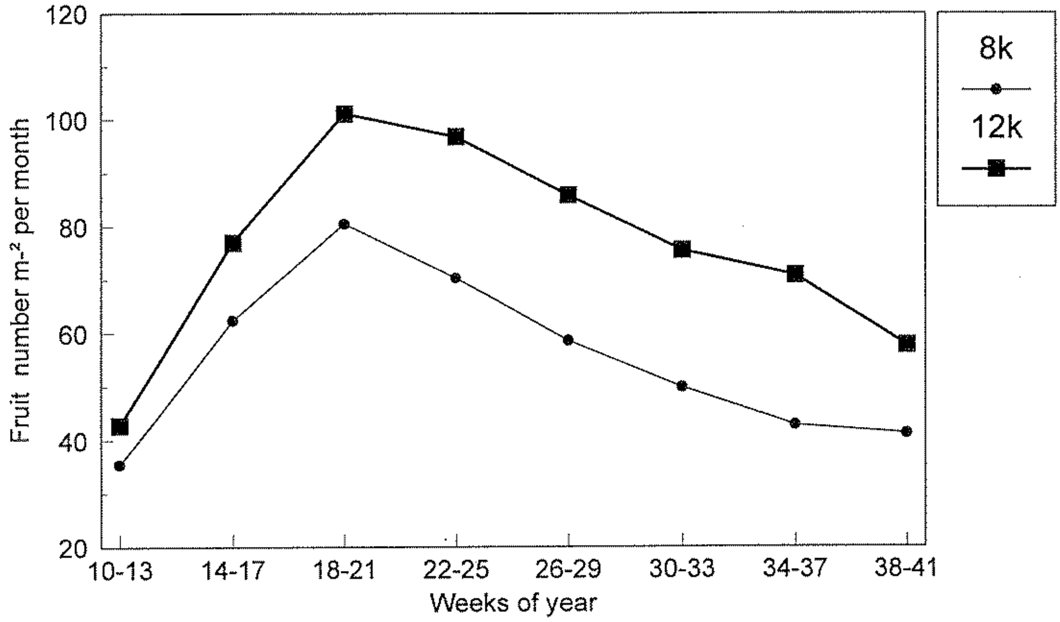
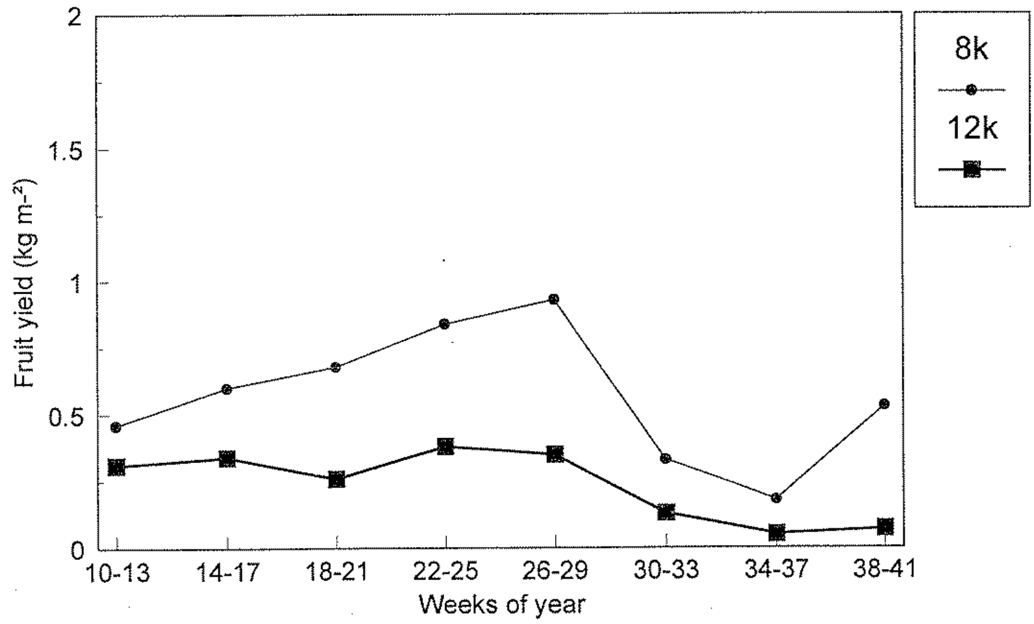


Fig. 8. The effects of crop density on yield of C grade fruit



The yield of C grade fruit increased each month up to weeks 26 to 29 at the lower plant density but then decreased, while that from the higher plant density did not change greatly (Fig. 8). As a result, the final cumulative yield of C grade fruit was much greater at the lower plant density (Fig. 11). The production of D grade fruit was unaffected by treatment until weeks 22 to 25 (Fig. 9), after which, the higher density produced the higher yield, and so also produced a higher final cumulative yield (Fig. 12). The bulk of the increase at the higher density was in the smaller component (Ds) of the D grade fruit (Fig. 12). The monthly yield of E grade fruit reached a maximum relatively early in the season in weeks 18 to 21 (Fig. 10), which was also when mean fruit weight was least (Fig. 6). The higher density produced the higher yield of E grade fruit in all months and the difference in final yield was substantial (Fig. 11).

It is of interest that the tendency for the yield of C grade fruit to decline towards the end of the season was reversed in weeks 38 to 41 in the low density treatment (Fig. 8), while the tendency for the yield of E grade fruit to increase towards the end of the season was also reversed in weeks 38 to 41, but only in the high density treatment (Fig. 10). In view of the nature of the changes and the timing of their occurrence, it seemed likely that they were associated with "stopping" the crop in week 39.

3. Effects of side shoots

One major effect of adding approximately 4126 side shoots per acre to each of the original plant densities was to increase marketable yield later in the season (Fig. 13). Side shoots began to contribute additional yield to the lower density treatment (8k + ss) from weeks 22 to 25 onwards (Fig. 13). The average effect of side shoots was not significant ($P > 0.5$), however, until weeks 30 to 37, when side shoots also began to contribute additional yield at the higher density (i.e. 12k + ss) (Fig. 13). The two treatments with the same effective density, i.e. 8k + ss and 12k, gave similar yields of marketable fruit per month from about week 26 onwards. The pattern of effects on Class I yield (Fig. 14) was broadly similar to that for marketable yield, though the effect of side shoots became significant earlier, in weeks 26 to 29.

The taking of side shoots in weeks 9 and 14 did cause some reduction in yield in weeks 10 to 21, especially at the higher density in which yield was reduced to that of the lower density without side shoots (i.e. 8k) (Fig. 13). The reduction was much less at the lower density and the average overall effect of side shoots on early yield was not significant. These reductions in early yield may represent either a diversion of assimilate from the main shoot to the developing side shoot or competition for light between the main shoot and the side shoot. Overall, the addition of side shoots increased final cumulative yields of marketable and Class I fruit by about 12% at the lower density, as compared with less than 3% at the higher density (Fig. 15). Even so, the final marketable yield at the lower density with side shoots (i.e. 8k + ss) was less than at the higher density without side shoots (i.e. 12k) (Fig. 15).

The addition of side shoots also allowed a greater number of Class I fruit to be picked per month from week 22 onwards at both of the initial plant densities (Fig. 16). As described earlier, in the absence of side shoots, the number of fruit picked per month increased to a maximum in weeks 18 to 21 and then decreased at both plant densities. The addition of side

Fig. 9. The effects of crop density on yield of D grade fruit

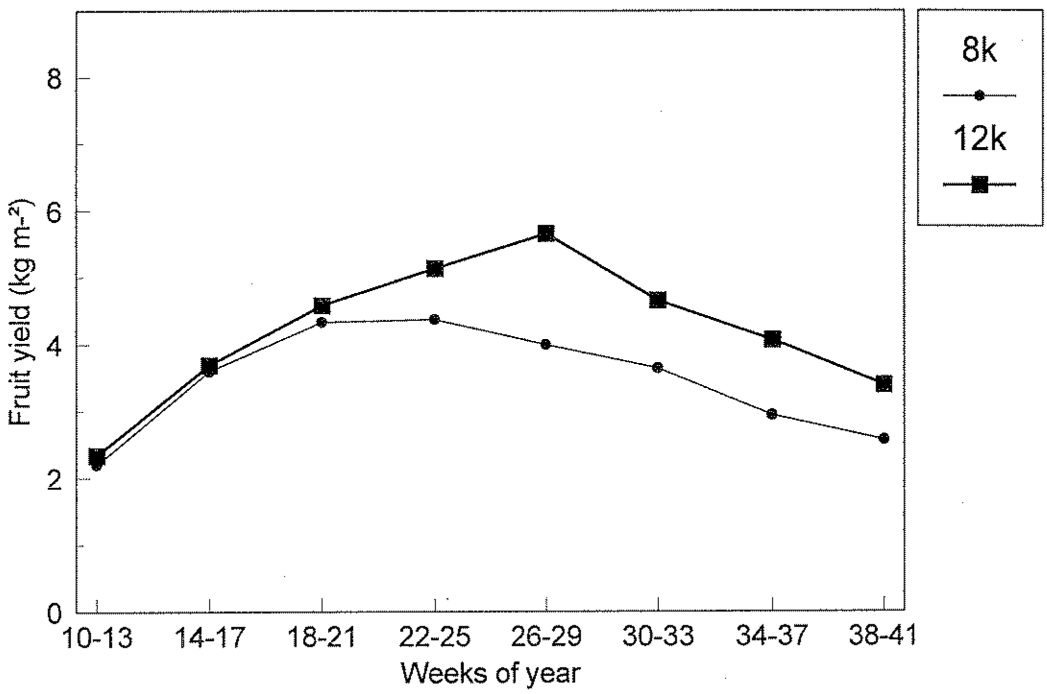


Fig. 10. The effects of crop density on yield of E grade fruit

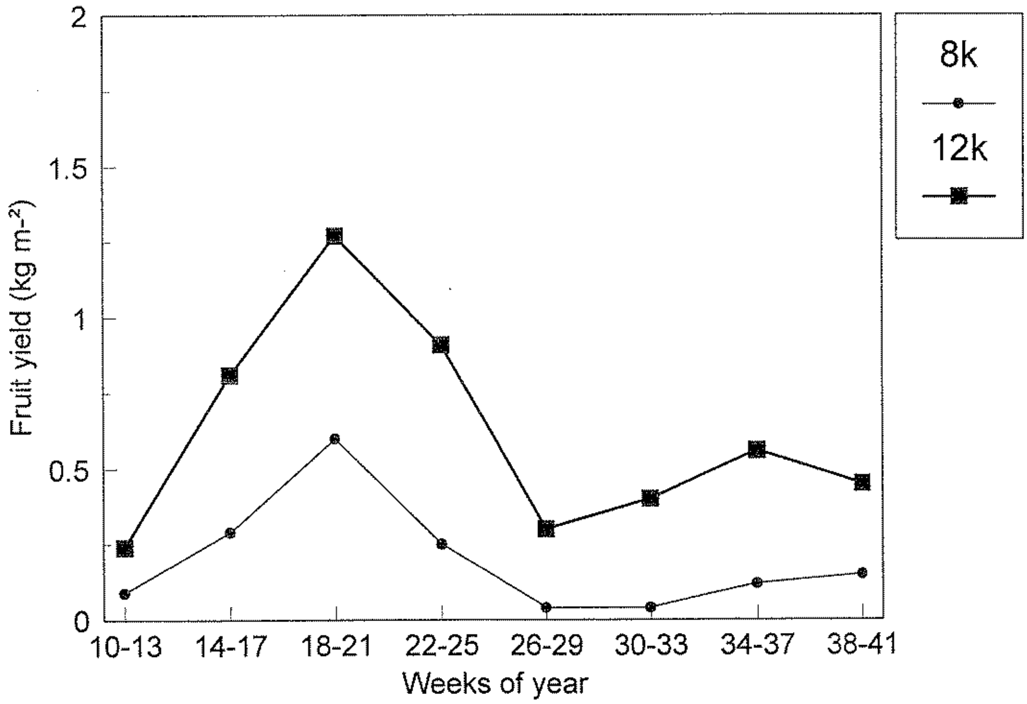


Fig. 11. The effects of crop density on final yield of C and E grade fruit

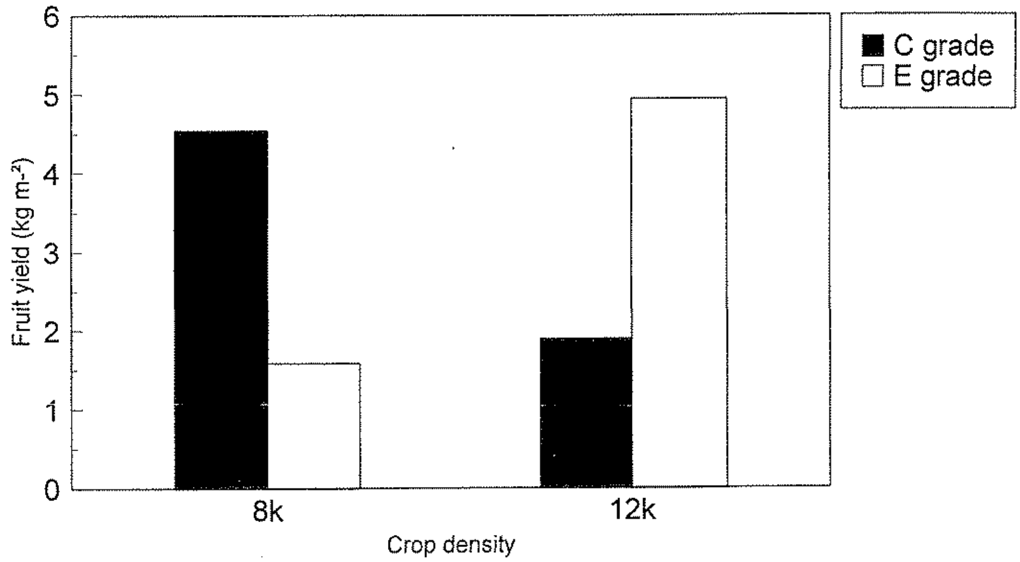


Fig. 12. The effects of crop density on final yield of D grade fruit

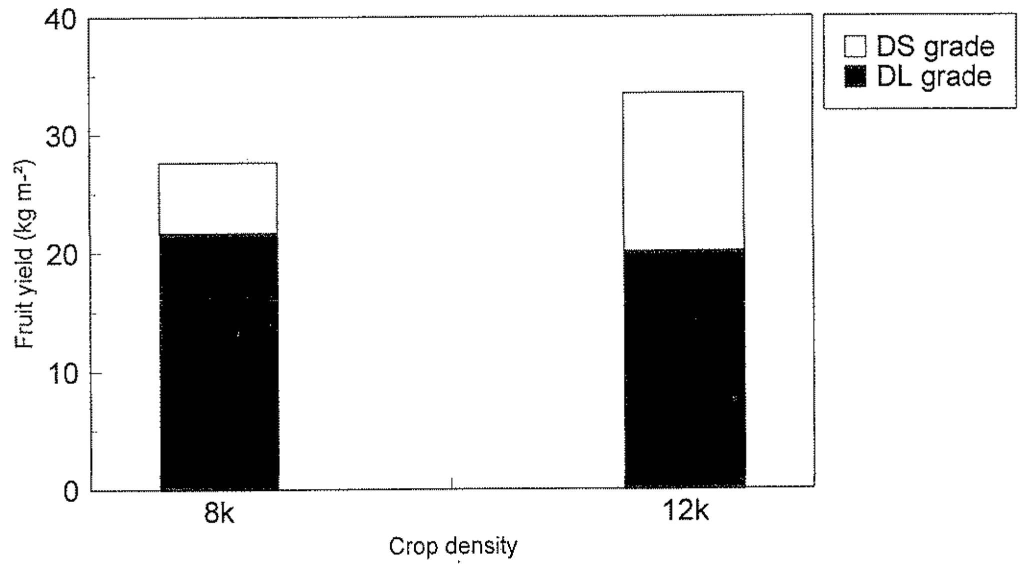


Fig. 13. The effects of side shoots on yield of marketable fruit

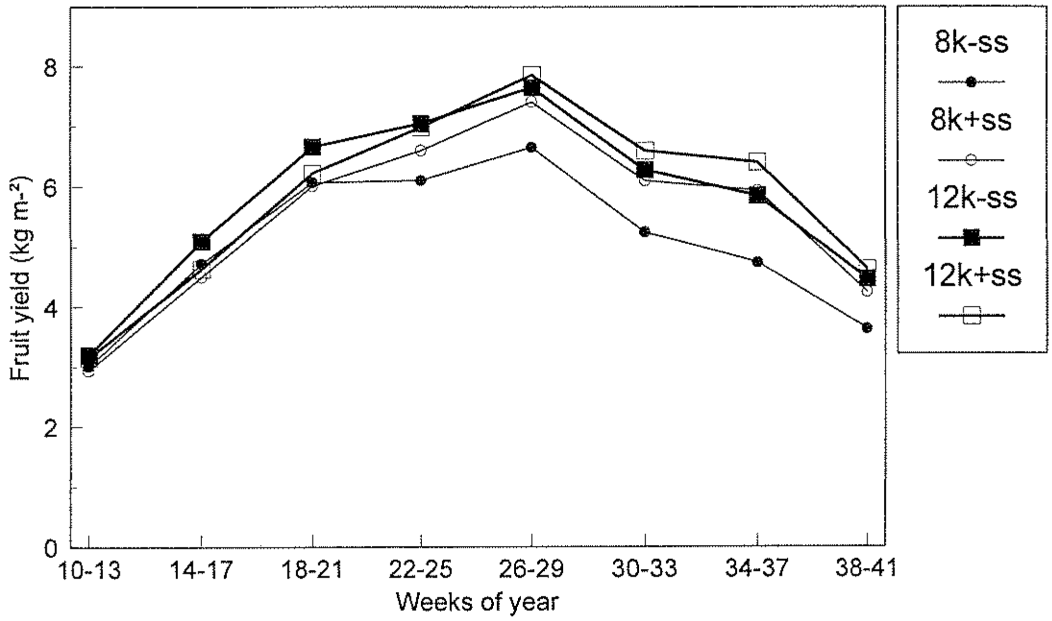


Fig. 14. The effects of side shoots on yield of Class I fruit

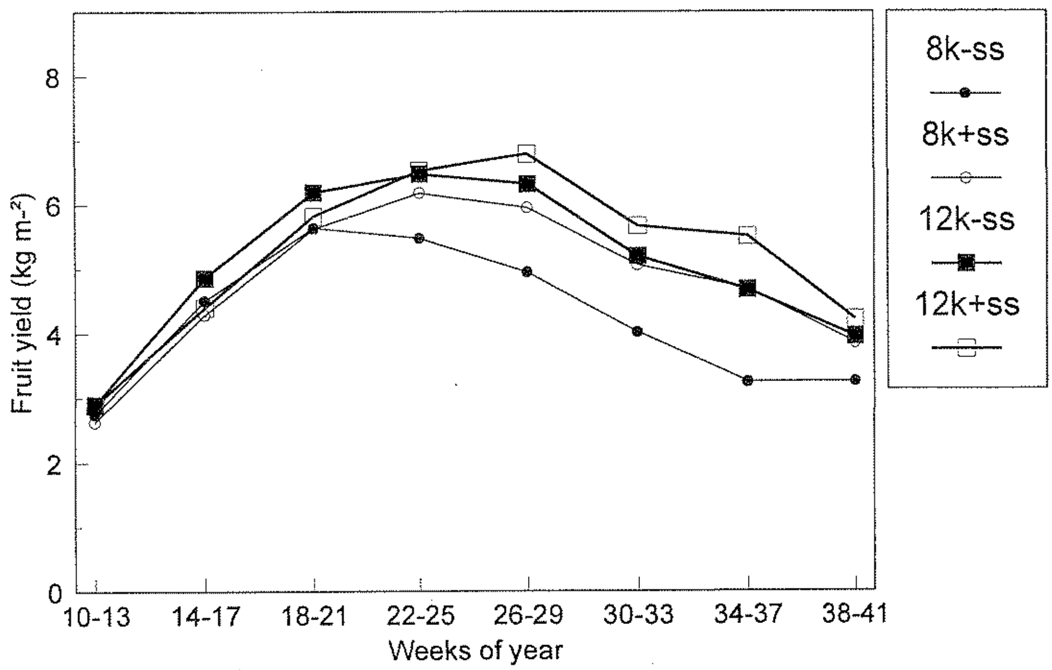


Fig. 15. The effects of side shoots on final yields of marketable and Class I fruit

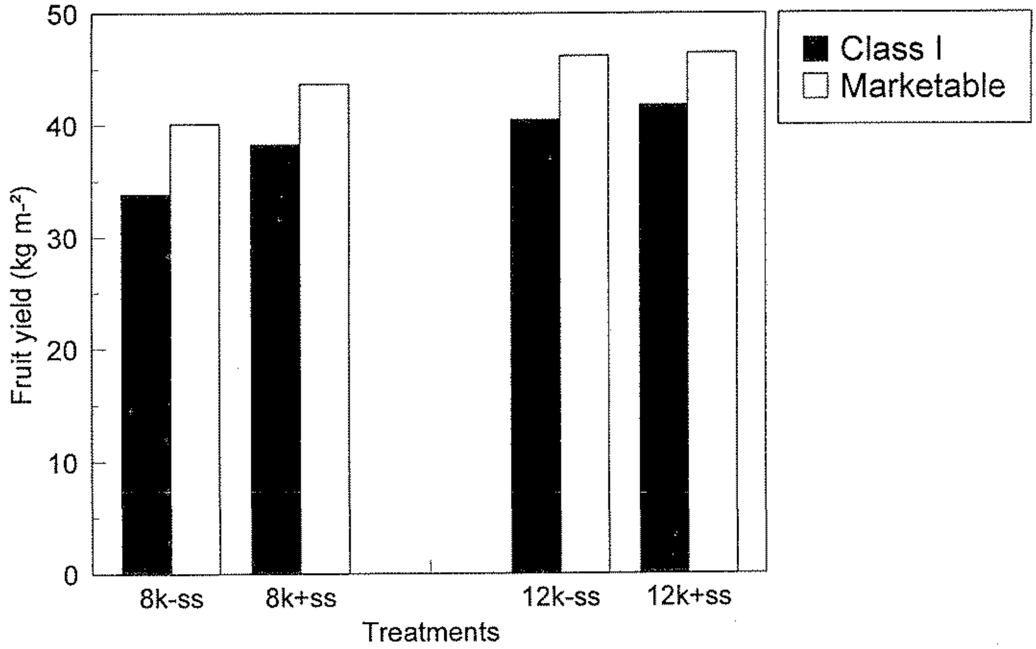
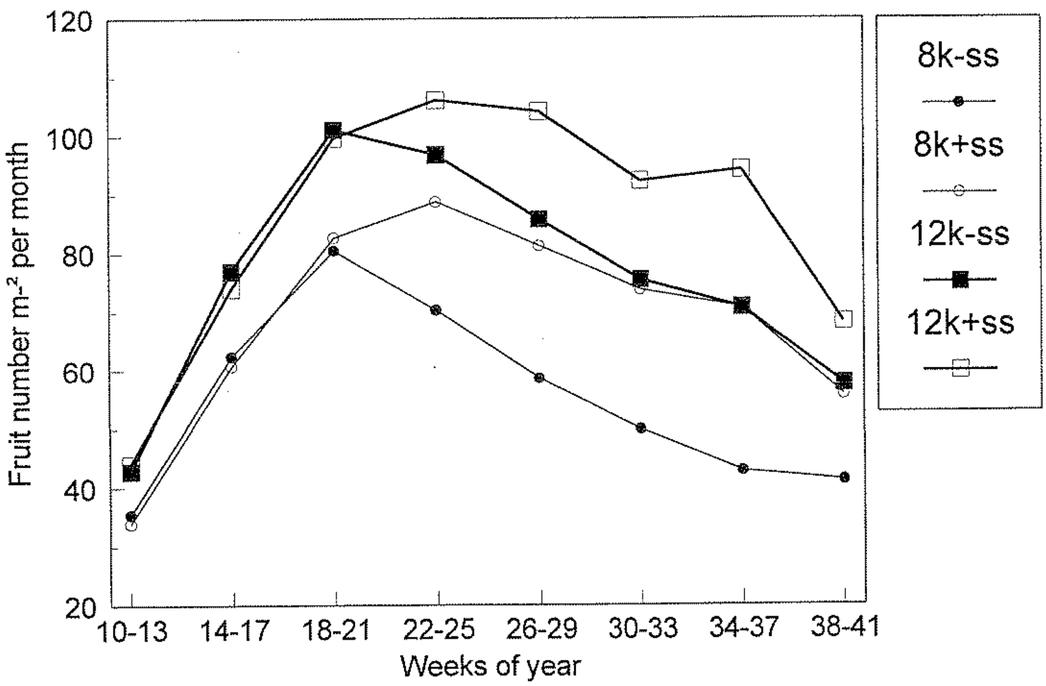


Fig. 16. The effects of side shoots on numbers of fruit picked per m² per month - Class I fruit



shoots delayed this decline until after weeks 26 to 29, by which time, the number of fruits produced per month was also similar in the two treatments with the same effective plant density, i.e. 8k+ss and 12k.

One consequence of these effects on yield and fruit number was that the presence of side shoots at either plant density, reduced mean Class I fruit weight in most periods, significantly so from week 22 onwards, and mean Class I fruit weight fluctuated less in the period from weeks 18 to 21 onwards in those treatments with side shoots (Fig. 17).

Side shoots had little impact on fruit size up to weeks 18 to 21 but, thereafter, the weight of C grade fruit produced in each successive four week period was reduced, especially at the lower density (Fig. 18), while the weight of D grade fruit was increased, but only at the lower density (Fig. 19), and the weight of E grade fruit was increased, especially at the higher density (Fig. 20). As mentioned earlier, the benefits of "stopping" were seen as a reduction in the yield of E grade fruit at the highest density (12k + ss) in weeks 38 to 41 and an increase in the yield of C grade fruit at low density (8k).

The final cumulative yields showed that while the yield of C grade fruit decreased with increasing plant density, that of E grade fruit increased (Fig. 21). The yield of D grade fruit was greatest in the 12k treatment, although the weight in the Ds fraction did increase with increasing density and with the addition of side shoots (Fig. 22).

4. Effects of truss thinning

The thinning treatment that was applied to the first three trusses, reduced the yields of marketable and of Class I fruit produced by trusses 1 and 2 but not of truss 3 (Appendix 4). Treatment also reduced the yields of D (especially Ds) and E grade fruit, from all three trusses (Fig. 23). From truss 4 and above, and for up to 16 weeks after the thinning treatments began, the marketable and Class I yields were increased by treatment of the first three trusses, particularly in the C and D grades (Fig. 24). This increase almost compensated for the losses from trusses 1 and 2, particularly in marketable yield (Fig. 25), and presumably represented a redistribution of some of the assimilates that would have gone to trusses 1 and 2, if they had not been thinned. As a consequence of the reduction in yield of Ds and E grade fruit from trusses 1 and 2, the mean fruit weight was increased by almost 8g in the first four weeks of picking (Fig. 26).

5. Fruit quality

Neither initial plant density, the presence of side shoots, nor truss thinning had any consistent effects on the dry matter, sugar, or acid contents of fruits, when comparisons were made on fruit of the same size (D_L) and at the same stage of ripeness. The main influence on fruit quality was the time of year when fruit were picked. Generally, the dry matter content of the fruits (Fig. 27) increased from the first week of picking (week 10; 2 March) up to weeks 22 to 26 (25 May to 28 June). It then declined but increased again at week 32 (3 August). The sugar content of fruits also tended to increase to week 26 (Fig. 28) and then to decline, whereas °Brix appeared to increase slowly throughout the season (Fig. 29). The correlation

Fig. 17. The effects of side shoots on mean fruit weight - Class I

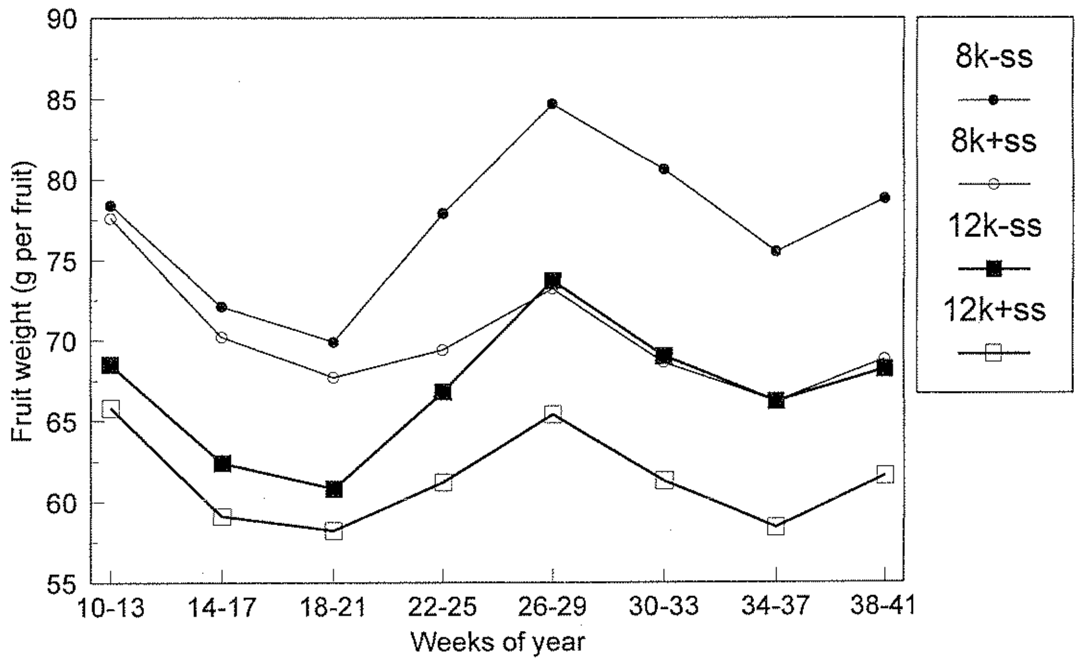


Fig. 18. The effects of side shoots on yield of C grade fruit

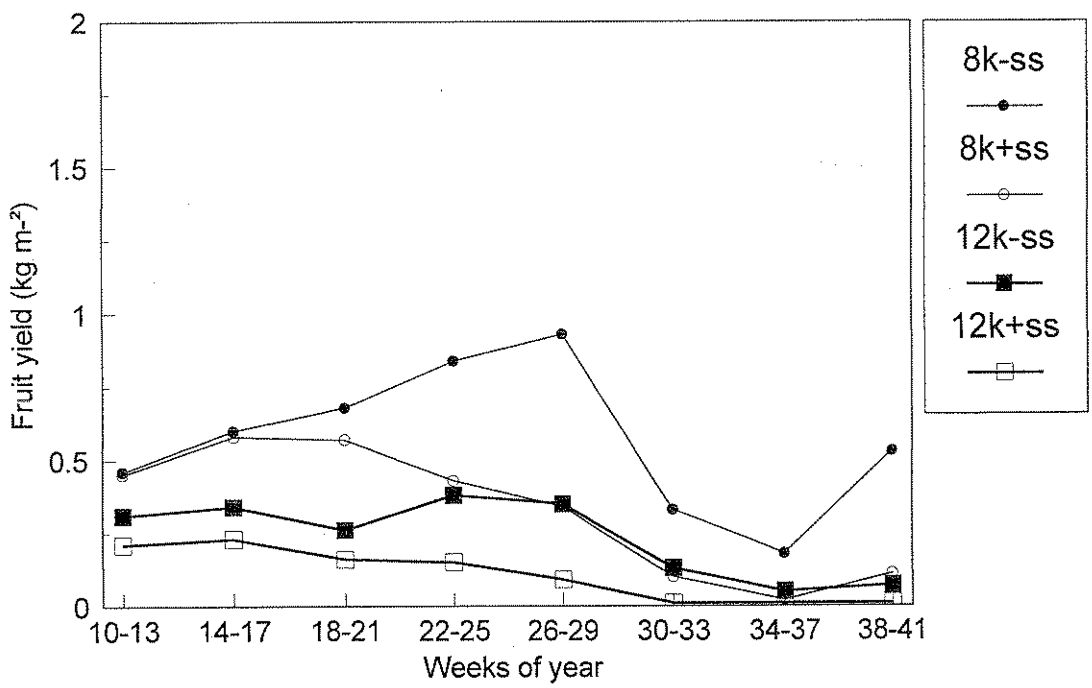


Fig. 19. The effects of side shoots on yield of D grade fruit

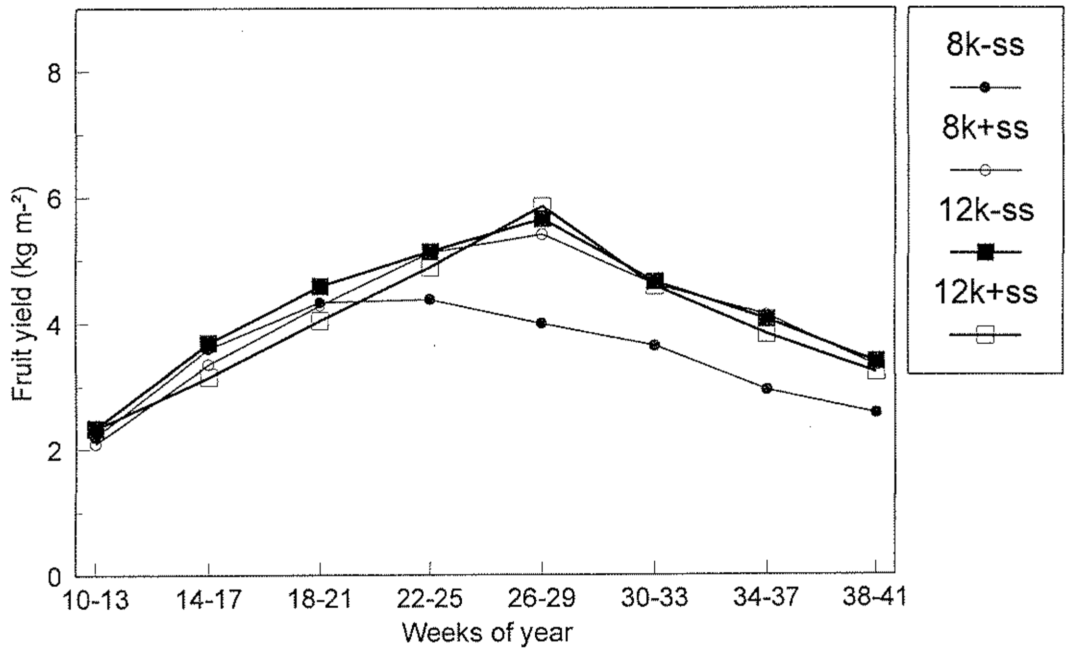


Fig. 20. The effects of side shoots on yield of E grade fruit

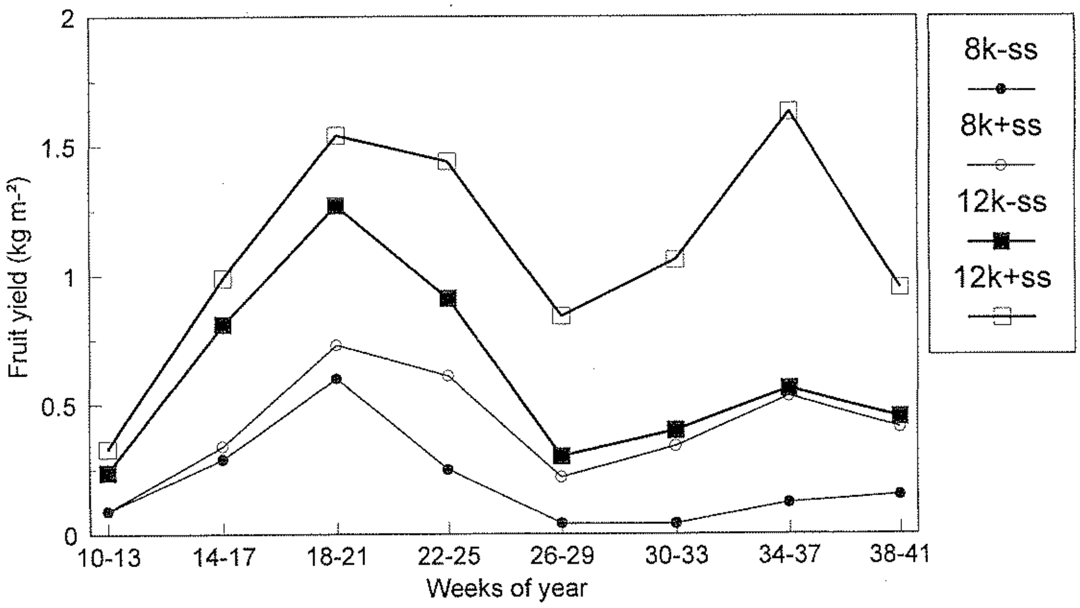


Fig. 21. The effects of side shoots on final yield of C and E grade fruit

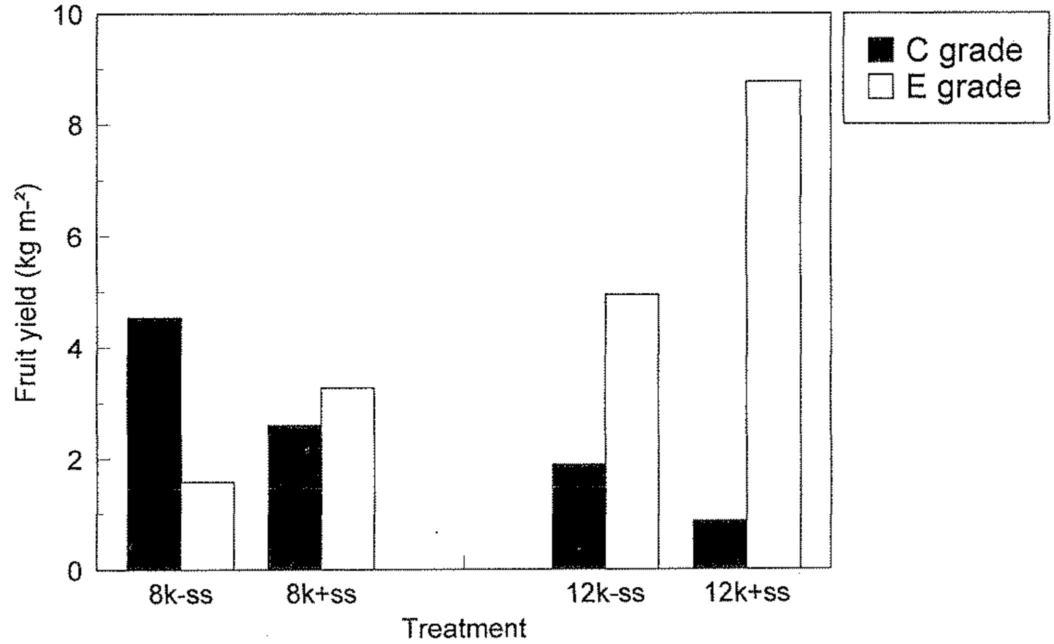


Fig. 22. The effects of side shoots on final yield of DL and DS grade fruit

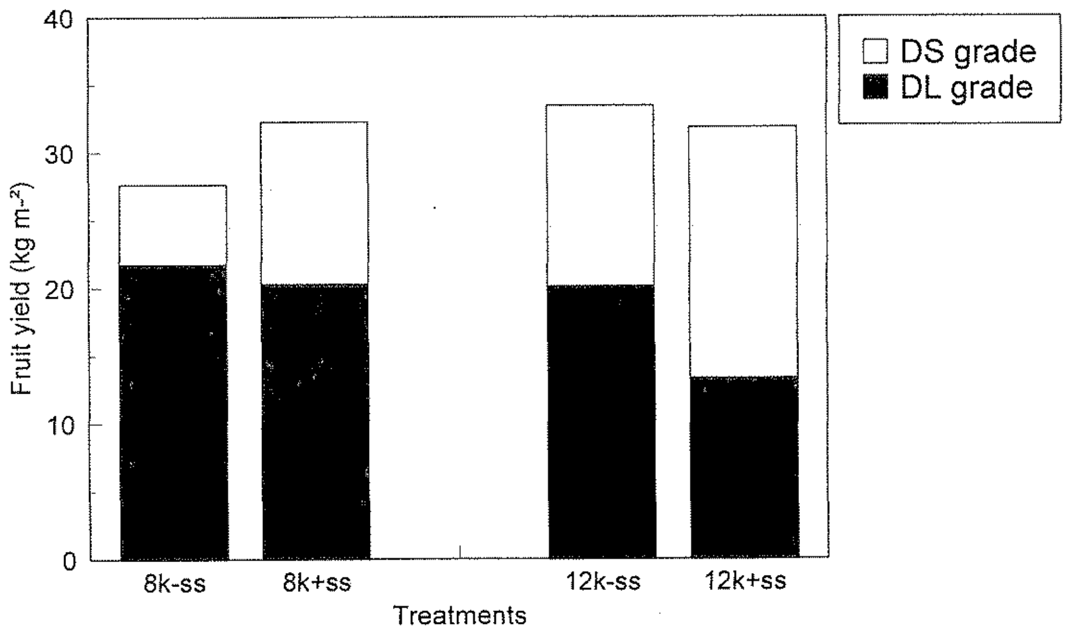


Fig. 23. Effects of truss thinning on yield of marketable fruit and its distribution between Classes and size grades - Trusses 1 to 3

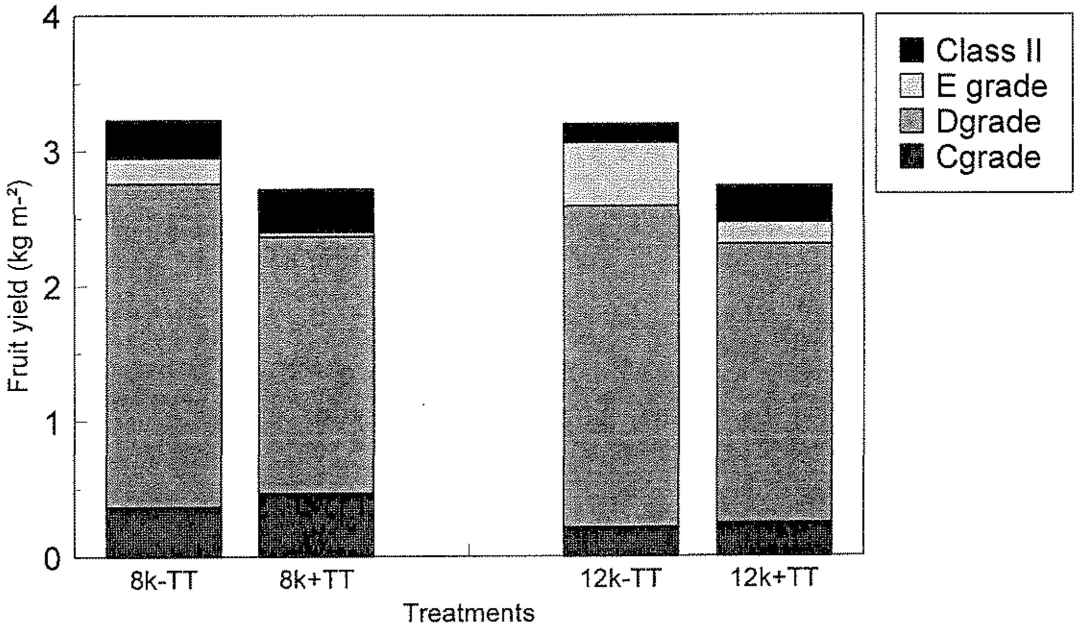


Fig. 24. Effects of truss thinning on yield of marketable fruit and its distribution between Classes and size grades - Trusses 4 and above, to week 21

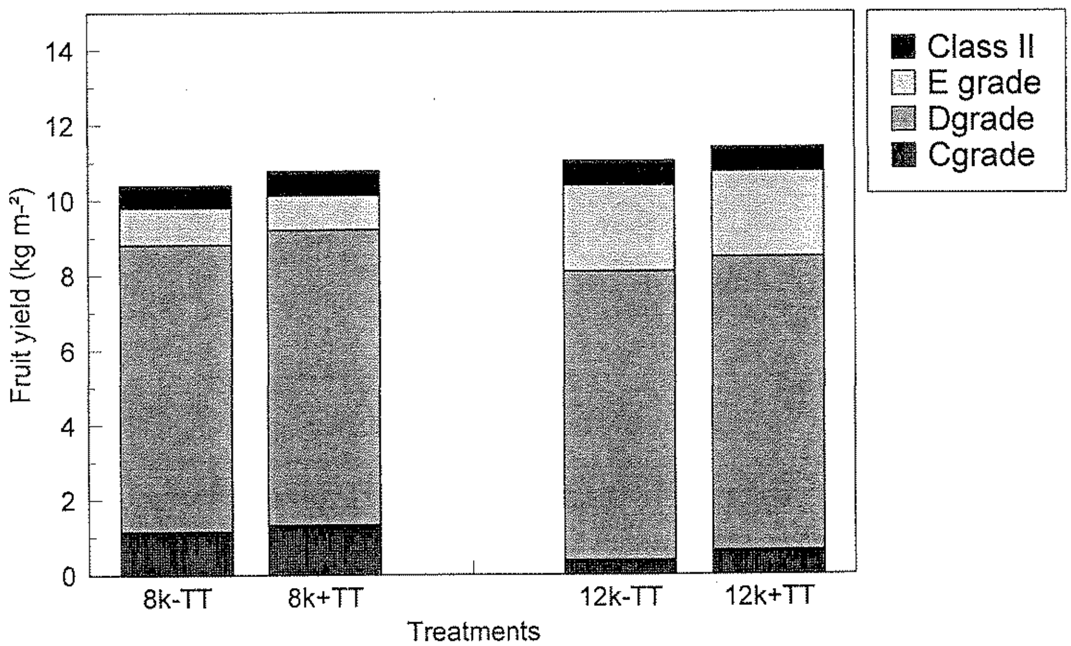


Fig. 25. Effects of truss thinning on yield of marketable fruit - Trusses 1 to 3 and higher trusses to week 21

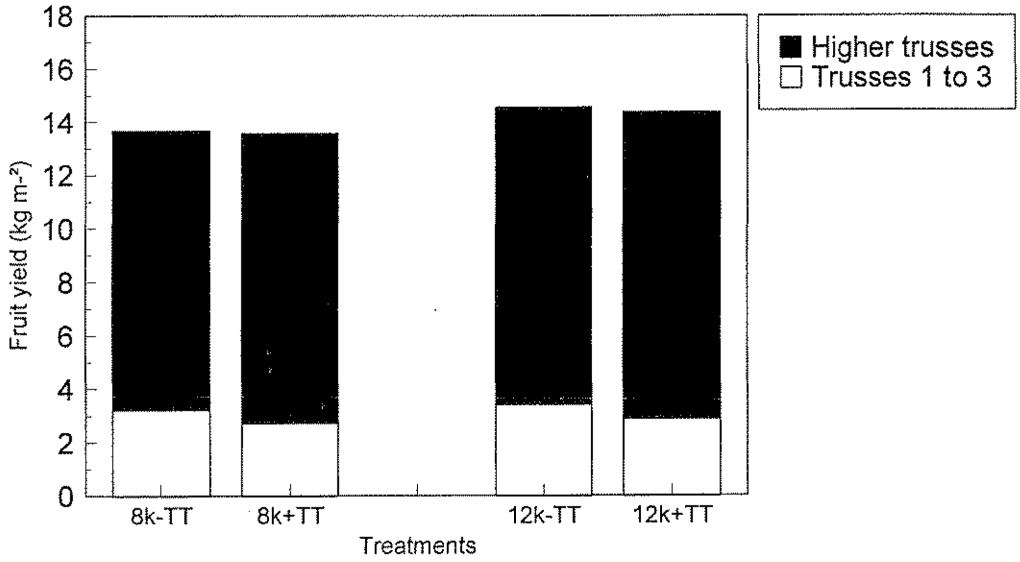


Fig. 26. Effects of truss thinning on mean fruit weight - Class 1

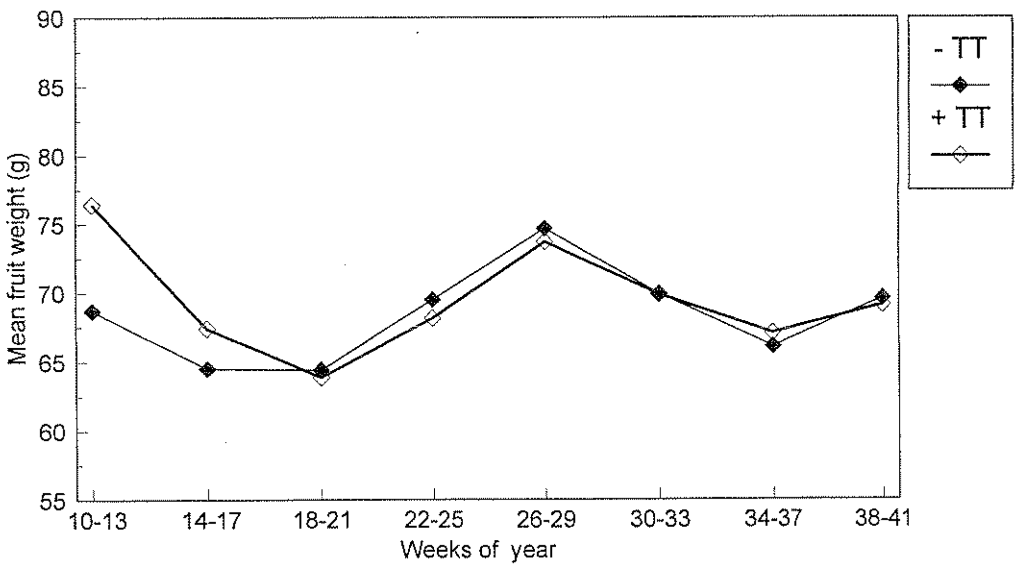


Fig. 27. Changes in dry matter content of fruit with time of year

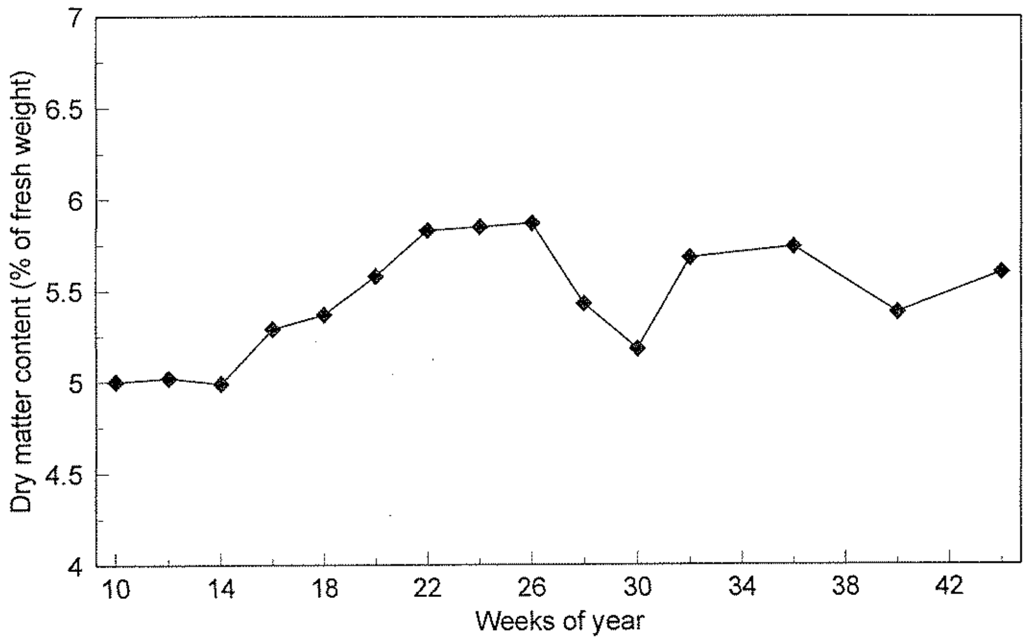


Fig. 28. Changes in sugar content of fruit with time of year

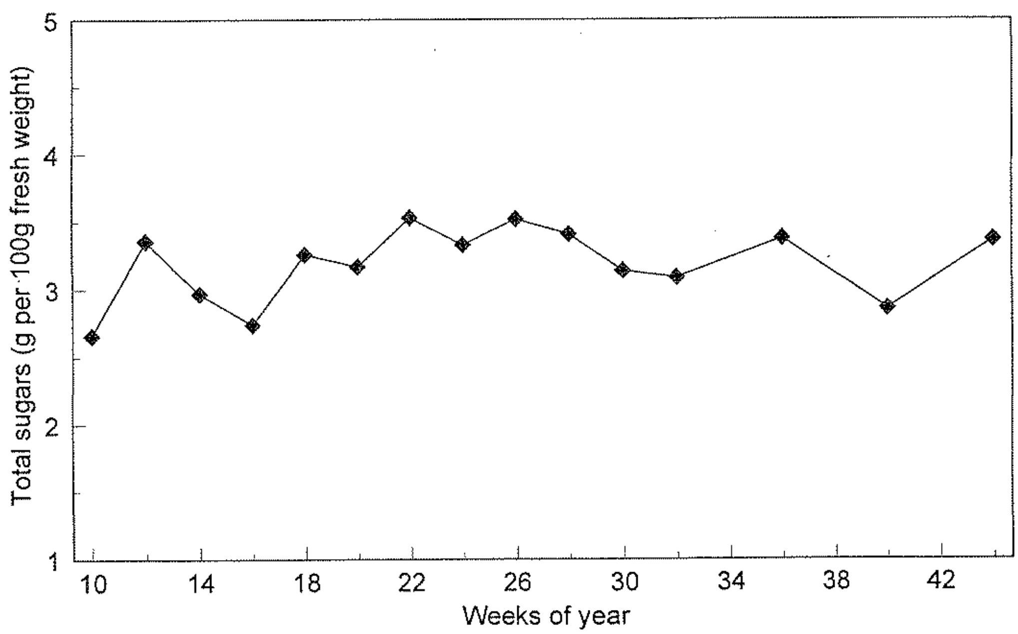


Fig. 29. Changes in °Brix of expressed fruit sap with time of year

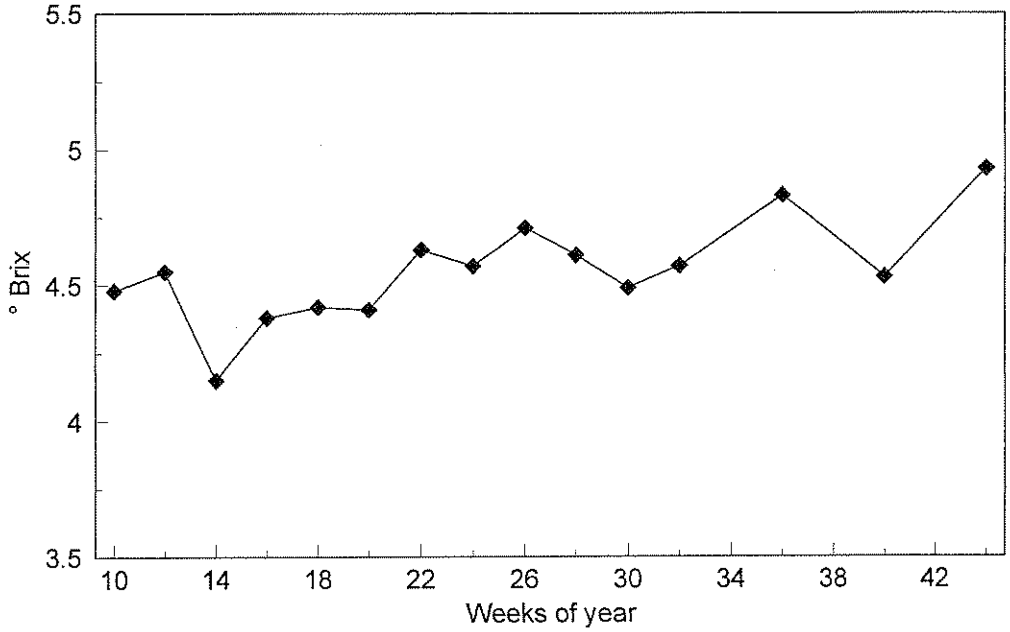


Fig. 30. The correlation between the sugar content of fruit and °Brix

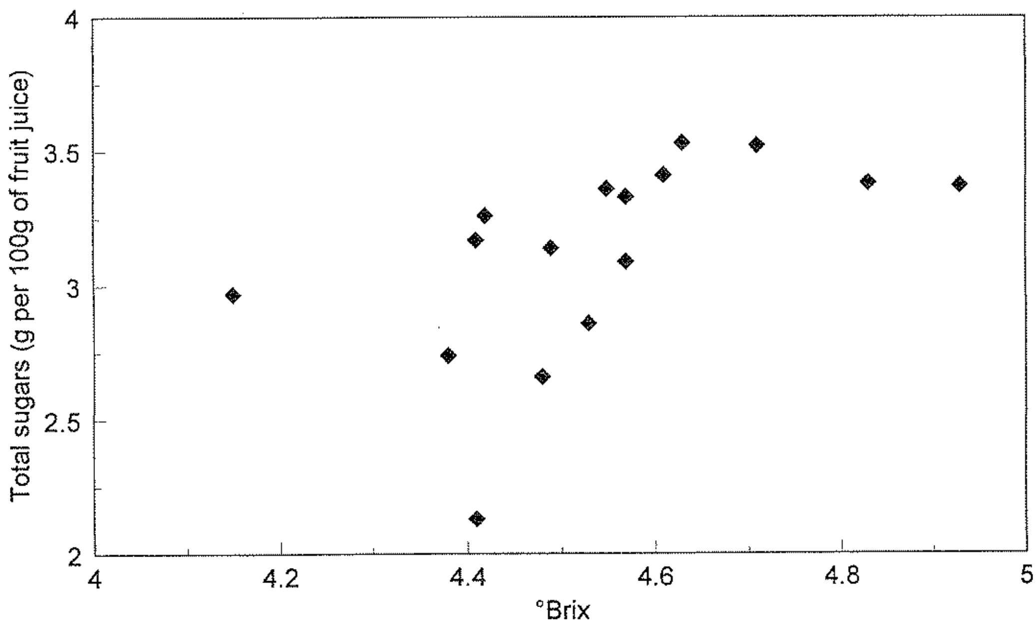
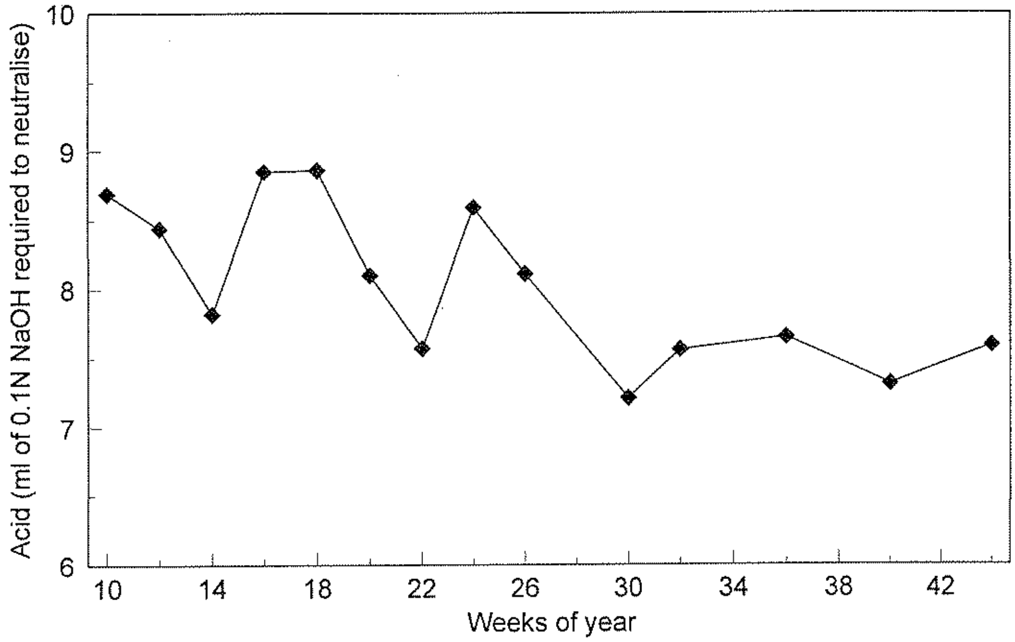


Fig. 31. Changes in acid content of fruit with time of year



between sugar content and °Brix was not consistent (Fig. 30). The acid content of fruits (Fig. 31) was more variable but tended to decline throughout the season.

As a result of the correlation with seasonal trends, the dry matter content of fruits was reasonably well correlated with incident solar radiation both in the three weeks before picking (Fig. 32) and over longer periods. In general, fruit picked after "stopping", especially those picked in week 44 (indicated as such on Fig. 32), had higher dry matter contents than might have been expected from the correlation with solar radiation. Most other aspects of fruit quality were less well correlated with incident solar radiation, especially fruit acidity, which appeared to be quite independent of incident solar radiation (Fig. 33).

Fig. 32. The correlation between fruit dry matter content and solar radiation in the three weeks prior to picking

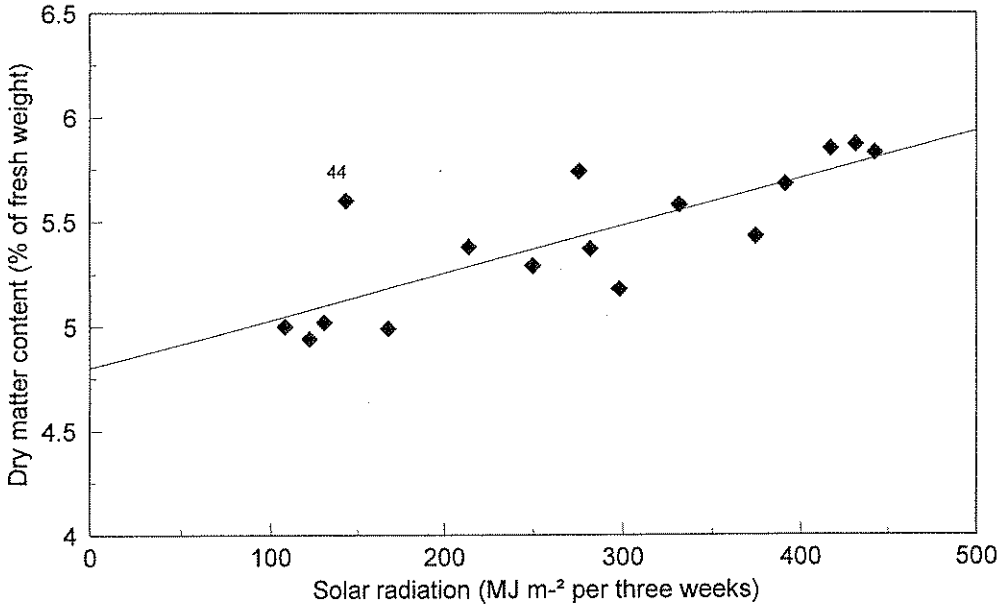
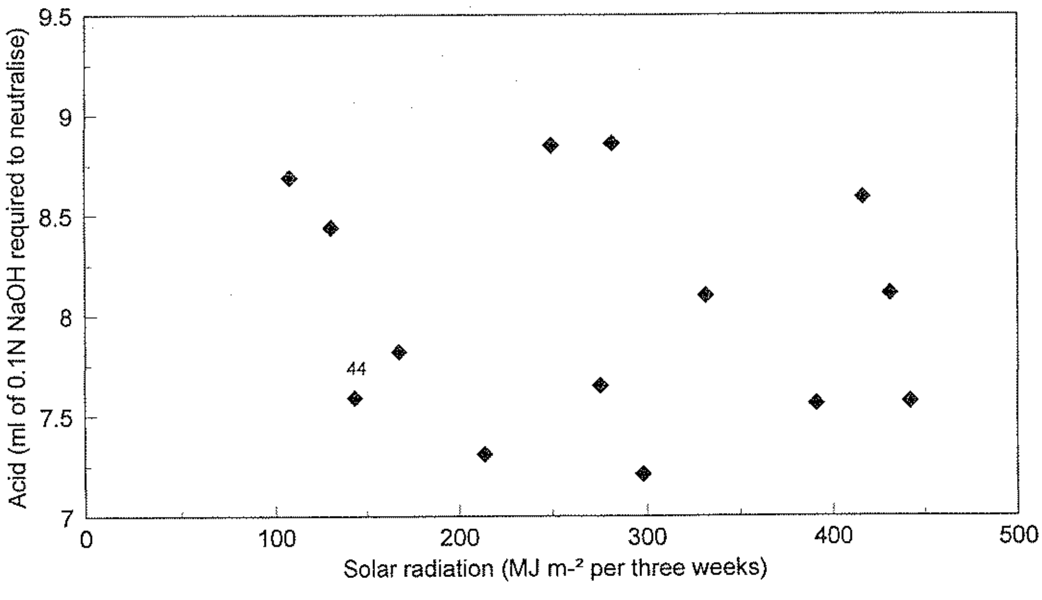


Fig. 33. The correlation between fruit acid content and solar radiation in the three weeks prior to picking



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 presumably increased the ratio of leaf area to ground area (i.e. leaf area index, LAI) which allowed the crop to intercept more light and thus to produce more assimilate and to increase fruit yield. The increase in plant density also increased the number of fruit trusses produced per m^2 of ground area and thus the number of fruit per m^2. The increase in fruit number, however, was proportionally greater than the increase in yield and so mean fruit size was smaller at the higher density throughout the picking season (Appendix 5a). Within Class I, the yield of E grade fruit was greatly increased by the higher plant density in the early part of the season, while the yield of D grade fruit was increased from mid-season onwards, and the yield of C grade fruit was reduced in the early- and mid-season periods. As expected, mean fruit weight reached a maximum value shortly after the crop had received its highest monthly total of solar radiation and then decreased as solar radiation levels declined. However, mean fruit weight rose a little at the end of the season following the removal of competion from young leaves and stems by "stopping". Furthermore, although solar radiation levels were low at the beginning of the season, the mean fruit weight of the first few fruit trusses was also relatively high. This probably occurred partly because these fruit developed without competition from older trusses, and partly because the data presented in Figs 6 and 17 are the averages of fruit both from thinned and unthinned trusses in the early stages (see Fig. 26 and Appendix 5c).

3. Side shoots

The addition of side shoots in weeks 9 and 14 created 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 may have slightly depressed early yields from the main stem and was more evident at the higher density where the competition would have been greater. As the side shoots developed, they caused an increase in LAI and, especially at the lower density, this led to an increase in assimilate production that was detectable as an increase in yield once fruit began to be picked from the side shoots, i.e. about 70 to 75 days after the side shoots were taken. Once this stage had been reached, the two crops with the same effective plant density, i.e. low density with side shoots and high density without, produced similar fruit yields with a similar distribution of fruit sizes. Adding side shoots at the higher plant density had little beneficial effect on yield indicating that the LAI produced by 12 376 plants per acre of 'Liberto' was sufficient to maximise yield under the conditions of the experiment. The side shoots did increase the number of fruit per m^2 and so mean fruit weight was reduced once these additional fruit began to be picked (Appendix 5b). The addition of side shoots, therefore, tended to increase the yield of small fruit at the higher density and to reduce the yield of large fruit at the lower density, but only increased the total yield of D grade fruit at the lower density. It also lessened the fluctuations of mean fruit weight with time.

4. Truss thinning

Fruit numbers were reduced by 30% on the first three trusses by truss thinning. This treatment reduced the yield of small fruit produced by these trusses but also reduced their overall production of marketable and Class I fruit by about 15%. However, this "lost" yield was recovered in trusses 4 and above as the assimilate that could not be used in the first three trusses was redistributed to higher trusses (Fig. 25).

5. Fruit quality

The only factors that consistently influenced the dry matter and sugar contents of the fruits were the solar radiation incident on the crop and the practice of "stopping" shoot growth so as to divert most assimilate to the developing fruit. The dry matter content of fruits, in particular, increased in summer and appeared to increase after "stopping".

6. Other practical considerations

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 would suggest that higher 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.

7. The future

Planting at an initial low density and then increasing the effective plant density by means of taking side shoots appears to be a promising way of increasing fruit numbers per m^2 in line with increases in solar radiation incident per m^2. The technique has the added advantage that fewer plants have to be purchased per cropped acre. At present, however, it is not known when is the optimum time for taking side shoots nor whether their taking should be staggered over a period of some weeks. Also, if it is beneficial to increase fruit numbers 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, although note must also be taken of the increased fruit size that would result from "stopping".

Truss thinning is also beneficial but further experiments are required so as to refine the technique. The data from this experiment suggest that more fruit could have been left on the first truss, as they were not in competition with older fruit, and that the thinning might have followed a pattern in which it became progressively more severe with increasing truss number up to the fourth or fifth truss.

In addition, all of the above aspects must be related to incident solar radiation and to average CO_2 concentrations.

Appendix 1

Timetable of events and of solar radiation receipt (MJ m^{-2} $week^{-1}$) in 1992.

Date	Week	Event	Solar radiation
23 Jan	4	Thinned truss 1	
29 Jan	5	Thinned truss 2	29.8
4 Feb	6	Thinned truss 3	30.9
	7		34.3
	8		37.1
26 Feb	9	First side shoots taken	36.7
2 Mar	10	Fruit picked from trusses 1 and 2	48.4
	11		45.6
19 Mar	12	Fruit picked from truss 3	57.4
	13		64.9
30 Mar	14	Second side shoots taken	86.4
6 Apr	15		98.6
	16		75.7
	17		107.8
	18		105.3
4 May	19		118.8
11 May	20	Fruit picked from first side shoot	142.4
	21		181.3
	22		148.5
1 June	23		87.2
8 June	24	Fruit picked from second side shoot	191.5
	25		152.7
	26		140.2
	27		81.6
6 Jul	28		111.5
	29		105.1
	30		141.0
	31		145.2
3 Aug	32		122.4
	33		103.0
	34		80.8
	35		92.0
	36		79.5
7 Sep	37		91.4
	38		69.7
21 Sep	39	Crop "stopped"	52.9
	40		68.4
9 Oct	41	Last fruit picked	51.0

Appendix 2

Effects of density and ± side shoots on tomato fruit yields (kg m^{-2})

Treatments	C	D_L	D_S	D	E	CII	Market
Weeks 10-13							
8k-	0.46	1.80	0.40	2.21	0.09	2.75	3.01
8k+	0.45	1.76	0.33	2.09	0.09	2.63	2.94
12k-	0.31	1.52	0.82	2.34	0.24	2.90	3.20
12k+	0.21	1.38	0.95	2.33	0.33	2.89	3.15
Density	*	*	**	n.s.	**	*	*
Side shoots	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Weeks 14-17							
8k-	0.60	2.65	0.95	3.60	0.29	4.51	4.72
8k+	0.58	2.31	1.04	3.35	0.34	4.29	4.50
12k-	0.34	2.04	1.65	3.69	0.81	4.86	5.09
12k+	0.23	1.44	1.71	3.15	0.99	4.40	4.63
Density	*	*	***	n.s.	***	n.s.	n.s.
Side shoots	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Weeks 18-21							
8k-	0.68	2.99	1.34	4.33	0.60	5.64	6.07
8k+	0.57	2.80	1.48	4.28	0.73	5.62	6.01
12k-	0.27	2.47	2.11	4.59	1.27	6.19	6.66
12k+	0.16	1.88	2.16	4.04	1.54	5.82	6.22
Density	*	*	***	n.s.	***	n.s.	n.s.
Side shoots	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Weeks 22-25							
8k-	0.84	3.57	0.80	4.36	0.25	5.48	6.10
8k+	0.43	3.34	1.77	5.11	0.61	6.18	6.60
12k-	0.38	3.22	1.91	5.13	0.91	6.48	7.05
12k+	0.15	2.25	2.63	4.88	1.44	6.53	6.99
Density	n.s.	*	***	n.s.	***	*	*
Side shoots	n.s.	*	***	n.s.	***	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.

Appendix 2 (Continued)

Effects of density and side shoots on tomato fruit yields (kg m^{-2})

Treatments	C	D_L	D_S	D	E	CII	Market
				Grades			
<u>Weeks 26-29</u>							
8k-	0.93	3.57	0.42	3.98	0.04	4.95	6.65
8k+	0.34	3.70	1.70	5.39	0.22	5.95	7.41
12k-	0.35	4.14	1.51	5.65	0.30	6.32	7.65
12k+	0.09	2.84	3.01	5.85	0.84	6.79	7.86
Density	**	n.s.	***	***	***	***	n.s.
Side shoots	**	*	***	***	***	***	n.s.
Interaction	n.s.	*	n.s.	**	**	n.s.	n.s.
<u>Weeks 30-33</u>							
8k-	0.33	3.16	0.48	3.64	0.04	4.02	5.23
8k+	0.10	2.68	1.92	4.61	0.34	5.06	6.09
12k-	0.13	2.91	1.74	4.65	0.40	5.20	6.27
12k+	0.01	1.61	2.97	4.58	1.06	5.67	6.59
Density	n.s.	**	***	***	***	***	**
Side shoots	*	**	***	***	***	***	**
Interaction	n.s.	n.s.	n.s.	***	n.s.	*	n.s.
<u>Weeks 34-37</u>							
8k-	0.18	2.14	0.80	2.94	0.12	3.24	4.73
8k+	0.02	1.92	2.21	4.13	0.53	4.69	5.92
12k-	0.05	1.93	2.13	4.06	0.56	4.68	5.84
12k+	0.01	0.82	3.01	3.83	1.63	5.51	6.40
Density	n.s.	**	***	***	***	***	**
Side shoots	n.s.	**	***	**	***	***	**
Interaction	n.s.	*	n.s.	*	**	n.s.	n.s.
<u>Weeks 38-41</u>							
8k-	0.53	1.89	0.68	2.57	0.15	3.25	3.63
8k+	0.11	1.82	1.50	3.32	0.41	3.85	4.24
12k-	0.07	1.92	1.47	3.39	0.45	3.93	4.46
12k+	0.01	1.14	2.08	3.22	0.95	4.22	4.62
Density	***	n.s.	***	n.s.	***	*	*
Side shoots	***	*	***	n.s.	***	n.s.	n.s.
Interaction	**	n.s.	n.s.	*	***	n.s.	n.s.

Appendix 3

Effects of density and ± side shoots on final fruit yield (kg m^{-2})

Grades

Treatments	C	D_L	D_S	D	E	CII	Market
8k-	4.54	21.77	5.87	27.64	1.58	33.85	40.14
8k+	2.60	20.33	11.95	32.28	3.27	38.26	43.71
12k-	1.89	20.16	13.33	33.49	4.94	40.54	46.22
12k+	0.87	13.36	18.52	31.88	8.78	41.80	46.45
Density	*	*	***	*	***	**	*
Side shoots	n.s.	*	***	n.s.	***	*	n.s.
Interaction	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.

Appendix 4

Effects of ± truss thinning on tomato fruit yields (kg m^{-2})

	Grades						
Treatments	C	D_L	D_S	D	E	CII	Market
Truss 1							
8k-	0.10	0.70	0.23	0.93	0.08	1.11	1.23
8k+	0.16	0.69	0.06	0.75	0.00	0.91	1.01
12k-	0.08	0.53	0.36	0.90	0.15	1.13	1.27
12k+	0.08	0.64	0.23	0.87	0.04	0.99	1.09
Density	n.s.	n.s.	**	n.s.	**	n.s.	n.s.
Truss thin	**	n.s.	***	*	***	***	***
Interaction	**	n.s.	n.s.	**	n.s.	n.s.	n.s.
Truss 2							
8k-	0.13	0.50	0.19	0.78	0.05	0.96	1.06
8k+	0.12	0.51	0.04	0.55	0.00	0.68	0.80
12k-	0.09	0.41	0.38	0.79	0.17	1.07	1.17
12k+	0.09	0.41	0.18	0.59	0.05	0.73	0.82
Density	n.s.	n.s.	***	n.s.	***	n.s.	n.s.
Truss thin	n.s.	n.s.	***	**	***	***	***
Interaction	n.s.	n.s.	n.s.	n.s.	***	n.s.	n.s.
Truss 3							
8k-	0.14	0.49	0.19	0.67	0.06	0.88	0.94
8k+	0.19	0.52	0.08	0.60	0.03	0.83	0.93
12k-	0.05	0.35	0.34	0.69	0.15	0.91	0.97
12k+	0.08	0.47	0.26	0.74	0.07	0.89	0.97
Density	***	n.s.	**	n.s.	**	n.s.	n.s.
Truss thin	n.s.	n.s.	**	n.s.	***	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.

Appendix 4 (continued)

Effects of ± truss thinning on tomato fruit yields (kg m^{-2})

Treatments	Grades						
	C	D_L	D_S	D	E	CII	Market
Trusses 4 and above (to week 17)							
8k-	0.52	2.43	1.01	3.44	0.30	4.26	4.45
8k+	0.72	2.59	0.92	3.52	0.27	4.52	4.74
12k-	0.20	1.70	1.64	3.35	0.93	4.50	4.72
12k+	0.41	1.86	1.73	3.59	0.82	4.83	5.05
Density	*	*	***	n.s.	**	n.s.	n.s.
Truss thin	*	n.s.	n.s.	n.s.	n.s.	**	***
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Week 18 to 21							
8k-	0.64	2.87	1.36	4.23	0.69	5.60	5.99
8k+	0.61	2.92	1.46	4.39	0.64	5.66	6.09
12k-	0.19	2.31	2.07	4.38	1.35	5.99	6.43
12k+	0.24	2.04	2.21	4.25	1.46	6.02	6.44
Density	*	*	***	n.s.	***	n.s.	n.s.
Truss thin	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Appendix 5

Average Effects on Mean Fruit Weight (Class I)

a) Density

Weeks of year	8k	12k	sed	Sig.
10-13	78.00	67.12	1.580	***
14-17	71.18	60.73	1.919	**
18-21	68.80	59.49	1.676	***
22-25	73.67	63.96	1.679	***
26-29	78.96	69.42	1.422	***
30-33	74.62	65.13	1.338	***
34-37	70.87	62.27	1.034	***
38-41	73.81	64.85	0.968	***

b) Side shoots

Weeks of year	-	+	sed	Sig.
10-13	73.45	71.67	1.580	-
14-17	67.26	64.65	1.919	-
18-21	65.36	62.94	1.676	-
22-25	72.34	65.29	1.679	**
26-29	79.22	69.17	1.422	***
30-33	74.78	64.97	1.338	***
34-37	70.84	62.31	1.034	***
38-41	73.49	65.18	0.968	***

c) Truss thinning

Weeks of year	-	+	sed	Sig.
10-13	68.68	76.44	0.692	***
14-17	64.51	67.40	0.340	***
18-21	64.42	63.88	0.690	-
22-25	69.49	68.15	0.724	-
26-29	74.68	73.71	0.571	-
30-33	69.90	69.85	0.681	-
34-37	66.09	67.06	0.834	-
38-41	69.58	69.09	0.998	-

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

PROPOSAL

1. Title: Contract No: PC65

REGULATION OF TOMATO FRUIT SIZE BY PLANT DENSITY AND TRUSS THINNING.

2. BACKGROUND AND COMMERCIAL OBJECTIVE

With long-season tomato crops, fruit picking can begin in February and continue until the following October. The market prefers Class I fruit in the D size grade i.e. 47-57 mm in diameter; 50-90 g in weight, and when grown at conventional plant densities, most of the fruit produced are in the desired grade, although there are marked seasonal trends. Early in the year, a high proportion of the fruit may be smaller than desired, especially when winter light levels are poor and when bees have been used to ensure good fruit set. In summer, the opposite trend is observed and too high a proportion of the fruit may be larger than desired.

There is good evidence that while assimilate production varies through the year in relation to natural light levels, the proportion of the assimilate that is distributed to the fruits of tomato remains relatively constant. Consequently, to achieve the objective of producing fruit of uniform size throughout the year, the number of fruit produced each week per unit area of production must be changed in relation to changes in light level. In theory, this could be done by changing either plant density or fruit number per truss through the year.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY

The financial benefits are difficult to assess as information about commercial contracts between growers and supermarkets is difficult to obtain. Sources in ADAS suggest that returns for fruit that are smaller than desired may be at least 10% less; smaller fruit may account for 25% of the total production of marketable fruit when the value of the fruit is at its highest and can account for up to 10% of total production over the whole season.

4. SCIENTIFIC/TECHNICAL TARGETS OF THE WORK

The project aims to establish whether it is possible to achieve improved uniformity of fruit size throughout the year and seeks to verify the prediction that fruit size is regulated by the availability of assimilate from photosynthesis and the numbers of fruit competing for this assimilate. The present model assumes that assimilate production is regulated by the amount of solar radiation incident on the crop; that a constant fraction of this assimilate is available for fruit growth, and that uniformity of fruit size could be attained by altering the number of fruit available per unit area of ground in relation to changes in the average level of solar radiation per unit area of ground. Fruit number will be altered by truss thinning, by initial plant density, and by taking side-shoots. The results should show whether the simple model is adequate and whether some or all of the techniques can be used in commerce.

5. CLOSELY RELATED WORK

The project would have close links with the government-funded (MAFF and DES) programmes on the regulation of fruit growth and development and the influence of environmental and internal factors on fruit growth that are in progress at HRI-Littlehampton.

6. DESCRIPTION OF THE WORK

In the first year, the proposal seeks to establish general principles concerning the effectiveness of different methods of regulating fruit number and their effect on fruit size and quality. These principles will be used to design an evaluation of the more promising methods to be conducted on a semi-commercial scale in a second year. The crop will be grown in an NFT system in the initial experiment but in the second year, the crop could be grown on rockwool.

Reducing the number of fruit per unit area of production per week can be achieved, either by reducing the initial plant density or by truss thinning, while increasing the number of fruit picked per unit area per week can be achieved either by increasing the initial plant density or the effective density, i.e. by allowing some plants to carry side-shoots.

In the first experiment, we propose to use two initial densities; a low density equivalent to 8176 plants per acre (2.02 plants per m^{-2}) and a medium density equivalent to 12 264 plants per acre (3.03 plants per m^{-2}). The effective densities of these two initial treatments will be increased by taking side-shoots so as to provide the equivalent of an additional 4088 heads per acre. This will raise the effective density of the low density treatment to 12 264 heads per acre and will raise that of the medium density treatment to 16 352 heads per acre (4.04 heads per m^2).

The additional heads will be obtained by taking a side-shoot from every other plant in the low density treatment, and from every third plant in the medium density. The side-shoots will be taken in two stages, one half of the additional shoots will be taken after anthesis of truss 8 (late February) and the other half after anthesis of truss 12 (late March).

This arrangement will provide the following four main treatments, each of which will be replicated three times within one glasshouse.

a) 8176 plants per acre throughout (low density).

b) 8176 plants per acre increased to 12 264 heads per acre by taking side-shoots from every other plant (low density + side-shoots).

c) 12 264 plants per acre throughout (medium density).

d) 12 264 plants per acre increased to 16 352 heads per acre by taking side-shoots from every third plant (medium density + side-shoots).

Each double row of each treatment will be divided in half and each half will be layered independently. The first three trusses of one half will be pruned while those of the other half will be left intact. The details of the truss thinning treatment will be agreed with the Project Co-ordinator when it is known how many fruit have been set on the respective trusses. The object, however, will be to produce a range of fruit numbers per m^2 at each of these truss positions.

Such an arrangement will allow production, fruit size and quality to be assessed over a wide range of plant densities and over the full range of natural changes in light levels. It will also allow an assessment to be made of the potential benefits of truss thinning and will compare the productivity at a specific density i.e. 12 264 heads per acre produced either by individual plants or by plants with side shoots.

An essential component of the initial experiment would be an assessment of fruit quality in terms not only of fruit size but also of chemical composition (e.g. dry matter, sugars, and acids) and firmness.

7. COMMENCEMENT DATE AND DURATION

The initial experiment will start immediately and will run for one year. The second experiment, on a semi-commercial scale, could then start in the following year.

8. STAFF RESPONSIBILITIES

Project leaders: Drs K.E. Cockshull and L.C. Ho.

Other staff: One assistant to undertake all analytical work and collation of data.

9. LOCATION

HRI Littlehampton.

10. COSTS

TERMS AND CONDITIONS

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

Signed for the Contractor (s)

Signature..

Position Station Administrator HRIL

Date 26 November 1991

Signed for the ~~Contractor (s)~~ Council.

Signature..

Position Chief Executive.

Date 2.12.91

~~Signed for the Council~~

Signature..

Position..

Date..