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TF 154

Apples and Pears: Investigation into the effects of root pruning on growth and cropping

Grower Summary

Headline

- Root pruning can provide good growth control with the effect being dependant on timing and distance of the treatment from the trunk.
- Root pruning at petal fall gives the greatest growth but may adversely affect fruit size in both Cox and Conference.

Background and expected deliverables

Cox, Bramley and to a lesser extent Conference production are heavily dependant on maintaining cropping and vegetative wood in balance. In many orchards tree vigour is excessive, requiring interventions with chemical growth regulators, summer pruning, etc. in order to try and maximise production and reduce year to year crop variations. The industry is vulnerable to the possible withdrawal of chemical growth regulators and organic growers have no proven methods of growth control.

Root pruning techniques have been shown to achieve significant reductions in shoot growth and increased flower production but the effects on fruit set have been variable and reductions in fruit size noted. More recent work particularly with Conference in Holland and Belgium has shown that by varying the timing of the pruning and by applying multiple treatments in a season, the effects on fruit size can be minimised whilst the reduction in shoot growth is maintained. Apart from some modest capital cost the treatment is simple to apply and within the scope of the majority of fruit growers given accurate agronomic information and advice based on research relevant to UK varieties and conditions.

Figure 1. Root pruning during the dormant season in Cox. Note the use of an angled blade on the right hand side of the picture in the treated rows and a vertical stabilising blade on the left hand side of the picture in the guard row.

The intended deliverables of this project were to develop non-chemical means of growth control that would:

- Provide a practical method for using root pruning to reduce or eliminate growers' dependence on chemical growth regulators
- Provide a greater understanding of the effect of root pruning on growth and cropping of Cox and Conference under UK conditions which will enable agronomists to adapt the technique to suit individual orchard situations
- Reduce any adverse environmental effects by eliminating sprays of plant growth regulators (PGR’s)
- Reduce costs as a normal PGR programme is estimated to cost between £145-£345 per hectare per season whereas the cost of two root pruning operations is estimated to be £120 per hectare giving a net saving of £25-£225 per hectare
- Provide satisfactory alternative strategies
- Develop methods for growth control for organic production

The number of treatment timings and combinations provided a range of results so no additional research or development is envisaged in order to meet the trial objectives. However, it may be necessary to investigate different irrigation and nutrient regimes within root pruned orchards. It is also envisaged that some way of mapping the root system without disturbing it would enable a more accurate means of measuring both the degree of root pruning and the response of the root system to the treatment, thus enabling growers and agronomists to prune more accurately.

Summary of the project and main conclusions

Shoot growth

When the results were averaged over the 2004, 2005 and 2006 seasons (Figures 2-3), root pruning reduced shoot growth with the petal fall treatment having the greatest effect and the single treatment in July having the least effect for both Cox and Conference. In all cases there was a greater reduction in growth with the closer 60cm treatment than the wider 90cm treatment. The reduced shoot length concurs with previous research where root pruning carried out at distances closer to the trunk resulted in a greater reduction in shoot length.

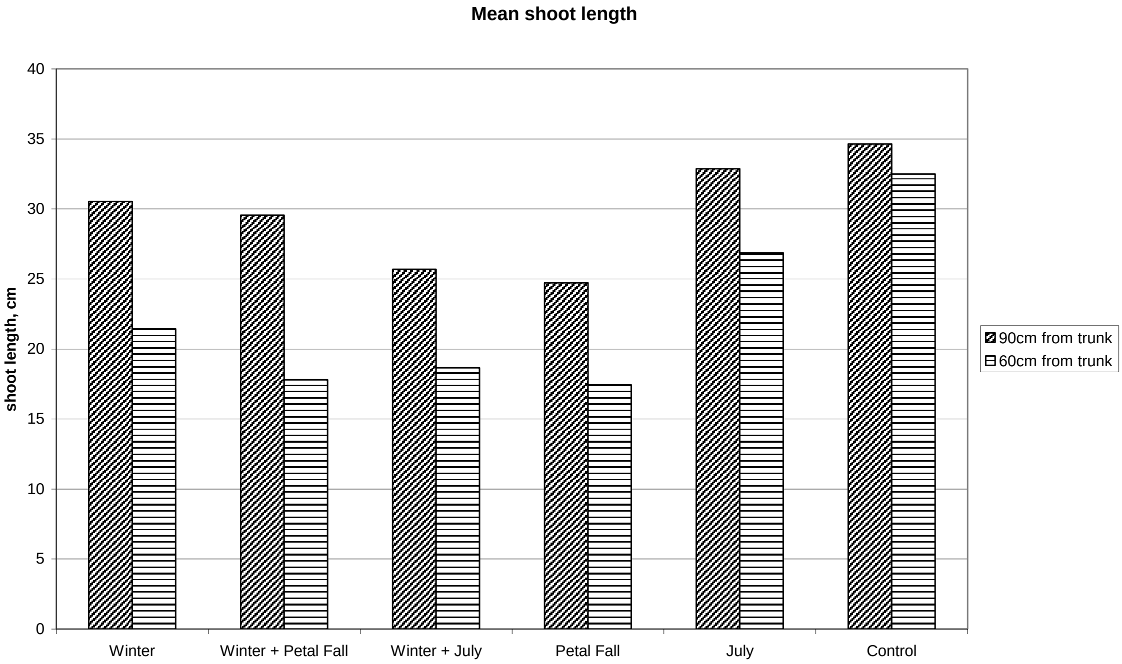


Figure 2. The effect of root pruning timings and distances on mean shoot length in cm (3 year average) for Conference (for the control columns, 90cm corresponds to blocks A & B and 60cm corresponds to blocks C & D).

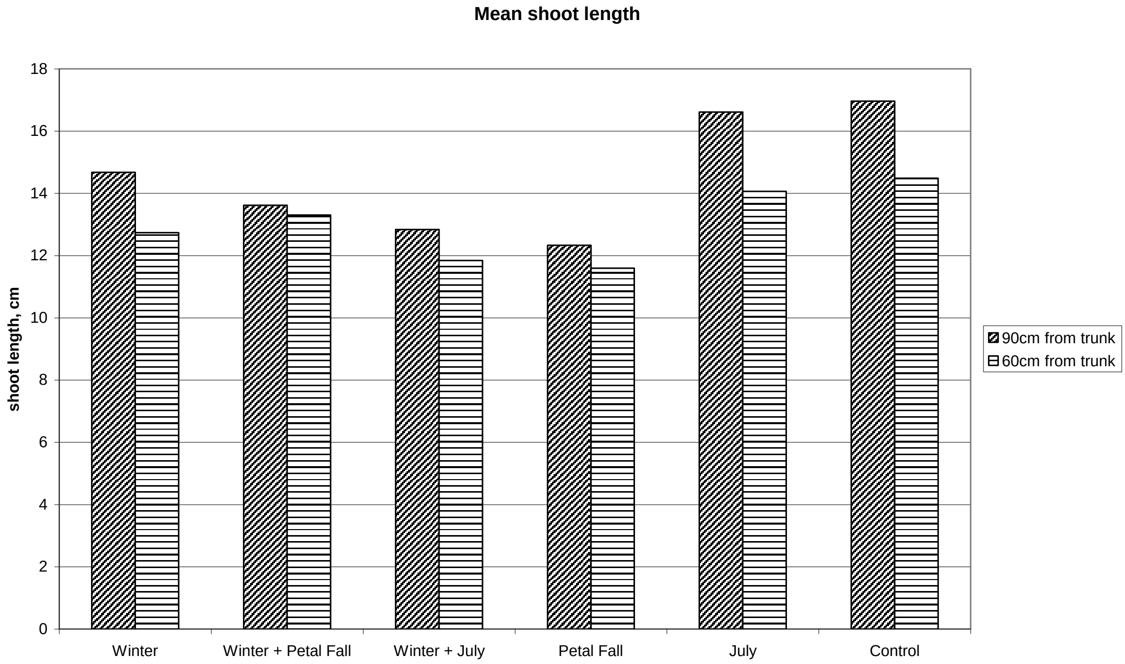


Figure 3. The effect of root pruning timings and distances on mean shoot length in cm (3 year average) for Cox (for the control columns, 90cm corresponds to blocks A & B and 60cm corresponds to blocks C & D).

Shoot numbers

The greatest reduction in shoot number was from the petal fall treatments, either alone or in combination. With Cox shoot number was reduced by 33% in both the single petal fall treatment and the combined winter plus petal fall treatment at 60cm from the trunk but other treatments had no effect on shoot number. In the case of Conference, petal fall pruning at 60cm from the trunk resulted in a reduction of shoot number by 54% and 71% for the winter plus petal fall treatment. Pruning at 60cm resulted in a 27-53% reduction in shoot number compared with pruning at 90cm for the different treatment timings.

Fruit size

Results for Cox in the dry 2006 season showed that where fruit numbers remain constant, fruit size is reduced when root pruning is carried out and that pruning at 60cm results in a greater reduction in fruit size than pruning at 90cm. The greatest reduction in average fruit size occurred when root pruning was carried out at petal fall - this resulted in a decrease in size of 3mm at a 90cm pruning distance and 7mm at a 60cm pruning distance compared with the control. However results for the combined three year period for Cox showed that there was no reduction in fruit size from either the 90cm or 60cm winter treatment or the 90cm July treatment compared with the control.

Results for Conference in the 2006 season again show that root pruning at 60cm caused a greater reduction in fruit size than pruning at 90cm when crop load is equal. Results for the three year average where fruit numbers are not significantly different between treatments shows that pruning at 90cm had no significant effect on fruit size. Pruning at 60cm resulted in a reduction in fruit size for all pruning timings with the greatest reduction (5mm) resulting from the petal fall treatment.

The reduction in fruit size has been reported to be linked to crop load, with a reduction in fruit size only occurring in trees with a high fruit number. This finding has been supported by results for the trial where a greater reduction in fruit size occurred with heavier crop load.

Flower number

No effect was observed on flower number or fruit set in either Cox or Conference over the three year period of the trial. However previous work has indicated that flower number and fruit set may increase in subsequent years of regular root pruning treatments.

Soil moisture

The positioning of the Enviroscan probes for measuring soil moisture corresponded with the most severe and least severe treatments. The Enviroscan showed that the trees treated in winter plus at petal fall actively extracted water from a greater depth from the soil profile than the control, indicating that the remaining roots were ‘working harder and deeper’ in both 2005 and 2006. In the winter plus petal fall treatment water infiltration did not occur to as great a depth in the soil profile compared to the control during late summer indicating that the soil had dried out to a greater extent for the winter plus petal fall treatment compared with the control. This drying of soil would cause water stress to the crop and is likely to account for the reduction in shoot length and fruit size observed.

Nutrient uptake

It was clear that root pruning affected nutrient uptake, which can be seen in the sap analysis and the nutrient availability in the soil solution which is shown in the soil analysis. Although the nutrient content of the soil solution under Cox and Conference was shown to vary with treatment and sampling time, results of sap and ‘Quicksoil’ analysis in each of the three years showed different levels relative to the control for each of the pruning treatments, there was no repeatable pattern to these results year on year.

Results from sap analysis showed that root pruning had affected nutrient uptake, probably due to the removal of roots where nutrient uptake occurred and subsequent stimulation of root regeneration. The timing of root pruning also interacts with nutrient uptake as nutrient demand varies across the season. This, coupled with differing timings of root removal and re-growth, caused nutrients to be taken up at differing rates.

As root removal reduces potential sites of nutrient uptake, the soil solution from unpruned trees could contain less of the measured nutrients than soil from root pruned trees. However this may be short-lived as after root pruning root regeneration occurs and regenerating roots have been shown to be more active in nutrient uptake than older roots.

When treatment results for leaf and fruit analyses were combined and compared with the control, no significant difference was detected in nutrient levels compared with the control. These results agree with previous third party work where root pruning was shown to have no effect on leaf nutrient levels in apple.

There therefore appears to be no need for supplementary fertilizer applications in root pruned orchards.

Pest and Disease

Between treatments there was no noticeable difference in the pest and disease status for either the Cox or the Conference over the three year period of the trial.

Conclusions

Overall, the trial has shown that root pruning provides a viable non-chemical means of achieving good levels of growth control. However at certain times and distances from the trunk fruit size can be reduced. By selecting the most appropriate timing and distance growers should be able to apply the technique with confidence.

- Results form each year of the root pruning trial have confirmed that growth control can be achieved by root pruning and that timing and distance from the trunk of the root pruning treatment has an effect on the amount of growth control.

- Root pruning at 60cm gives a greater reduction in average shoot length and shoot number than root pruning at 90cm.
- Root pruning at petal fall gives the greatest growth control.
- However, root pruning at petal fall at a distance of 60cm from the trunk adversely affected fruit size in both Cox and Conference.
- Fruit size was not increased by any of the root pruning treatments.
- Fruit size in Conference was not adversely affected by any of the 90cm root pruning treatments.

Action points for growers

- Where a major reduction in growth is required two treatments per year are better than one.
- Start with a dormant season treatment at least 6 weeks prior to bud burst and if growth is strong after petal fall or during the summer repeat the treatment.
- However, be aware that petal fall treatments appear to have the greatest effect on fruit size and should **only** be used if initial fruit set is poor due to adverse conditions during bloom.
- Where a less severe treatment is required just root prune in the winter.
- Root pruning too close to the trunk of the tree will reduce fruit size.
- As a guide, in this trial 60cm was approximately 50% of the distance from the trunk to the edge of the tree canopy and 90cm was 75% of the distance. Use these percentages rather than a strict distance when applying the results to your orchard.
- Monitor tree nutrient content regularly and apply supplementary nutrients as necessary
- Soil moisture conservation measures or irrigation should be considered especially in dry years to reduce adverse affects on fruit size.

Science section

Introduction

Cox, Bramley and to a lesser extent Conference production are heavily dependant on the use of the growth regulator Cultar to aid tree management and help reduce year to year crop variations. The industry is vulnerable to the possible withdrawal of Cultar and organic growers have no proven methods of growth control.

Root pruning techniques have been shown to achieve significant reductions in shoot growth and increased flower production but the effects on fruit set have been variable and reductions in fruit size noted. More recent work, particularly with Conference in Holland and Belgium, has shown that by varying the timing of the pruning and by applying multiple treatments in a season the effects on fruit size can be minimised whilst the reduction in shoot growth maintained. Apart from some modest capital cost the treatment is simple to apply and within the scope of the majority of fruit growers, given accurate agronomic information and advice based on research relevant to UK varieties and conditions.

APRC Contract Report (project SP136) Labour Reduction in apple and pear production refers to UK trials of root pruning, pp11 & 14 (Webster unpublished). Both ADAS and FAST have previously conducted observations in several orchards using a subsoiler rather than purpose built machinery. These studies showed that root pruning could (a) significantly reduce shoot growth (b) increase flower production (c) have variable effects on fruit set (d) cause reductions in fruit size.

Currently the industry relies heavily on a programme of 8-12 sprays of Cultar to achieve adequate growth control. Many growers will apply one or two of these sprays as a separate operation, the rest being applied with other routine sprays. Early sprays of Cultar require the addition of gibberellins to counteract the adverse effects of the product on fruit set and skin finish. Cultar is a very persistent chemical in the soil and might be withdrawn in the future for this reason.

Developing non-chemical means of growth control is therefore desirable in order to:

- Reduce any adverse environmental effects
- Reduce costs
- Provide satisfactory alternative strategies

- Develop methods for organic production

The cost of a normal growth regulator programme is estimated to be between £145 and £345 per hectare per season whereas the cost of two root pruning operations is estimated to be £120 per hectare giving a net saving of £25 to £225 per hectare.

Materials and methods

The trial was conducted at Parsonage Farm, Cobham, Kent by kind permission of Adrian Scripps Ltd and the farm manager Mr D. Hallendorff. The Cox (M9) and Conference (QC) orchards are well managed, approximately 8-11 years old and of moderate vigour (i.e. some growth control each year is beneficial) on a clay loam soil type. The Cox orchard had trickle irrigation and facilities to fertigate for the whole of the trial period whereas the Conference orchard only had these facilities in the third year of the trial. The farm owns suitable purpose built (by Dutch manufacturer) root pruning equipment and has experience using it.

Treatments were the same for both Cox and Conference and were applied with a root pruning blade of 50cm angled at 35^0 from vertical, at two distances from the trunk to both sides of the tree row:

(1) 60 cm from the tree trunk (50% of the distance from the trunk to the edge of the tree canopy)
(2) 90 cm from the tree trunk (75% of the distance from the trunk to the edge of the tree canopy)

The treatments were applied at the following times to assess differences due to application timing:

(1) Dormant period i.e. winter
(2) Petal Fall
(3) Early July
(4) Dormant period and Petal Fall
(5) Dormant period and Early July
(6) Control, unpruned

Where repeated treatments were applied the root pruning blade was placed in the same slot as in the earlier treatment. Next to each treated row was a guard row that was root pruned one side only with a vertical blade. This is indicated in Figure 4.

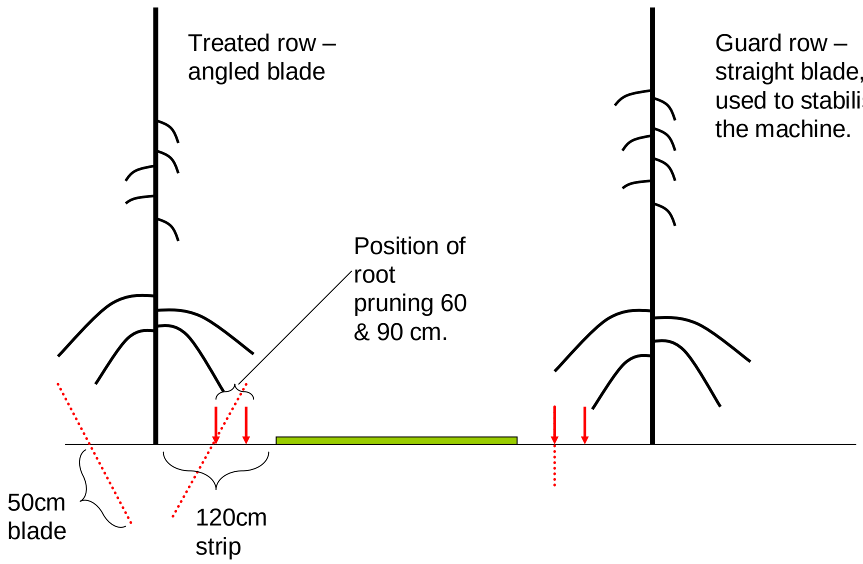


Figure 4. Diagram of treatment application.

The treatment timings were applied to single rows with one half of the row being root pruned at 60 cm from the trunk and the other half of the row being pruned at 90 cm from the trunk. The layout for the treatments is shown in Appendix I.

Figure 5. Setting the blade of the root pruner to 90 cm from the tree on Cox.

Figure 6. The root pruning blade prior to insertion into the soil.

Figure 7. Root pruning on Conference.

In the case of Cox there were two replicate blocks of 25 trees for each treatment and four replicate blocks of 25 trees for the control. For Conference there were two replicate blocks of 15 trees for each treatment and four replicate blocks of 15 trees for the control. As each plot was relatively large and the trial was aiming to produce commercial guidelines it was felt that a more complicated and replicated experimental design was unwarranted.

Soil moisture monitoring equipment (Enviroscan) was installed during the spring of year 1 of the trial for two treatments and the control in both Cox and Conference. The positioning of the probes corresponded with the most and least severe treatments. This equipment was used to measure soil moisture throughout the period of the trial.

Within each plot the following were recorded:

- Extension growth (mean of all the shoots on 3 trees per plot)
- Shoot number (on 3 trees per plot)
- Fruit size (200 fruits per plot)
- Flower numbers on a scale of 1-10 (a visual assessment with a score for each plot)
- Initial fruit set at approximately 15mm stage on a scale of 1-10 (a visual assessment with a score for each plot)
- Yield (fruit numbers on 5 trees per plot)
- Soil moisture
- Nutritional status
    - 4 sap analyses per plot (2 leaves from each tree in the plot)
    - 4 soil solution analyses per plot (25 soil cores from each plot)
    - 2 leaf analyses per plot (2 leaf clusters from each tree in the plot)
    - 1 fruit analysis per plot (1 fruit from each tree in the plot)
- Pest and disease status (a visual assessment of each plot at monthly intervals)

Results

Effects of root pruning on extension growth

The mean extension growth in cm (of all the shoots on 3 trees per plot) in 2006 was recorded and is presented below:

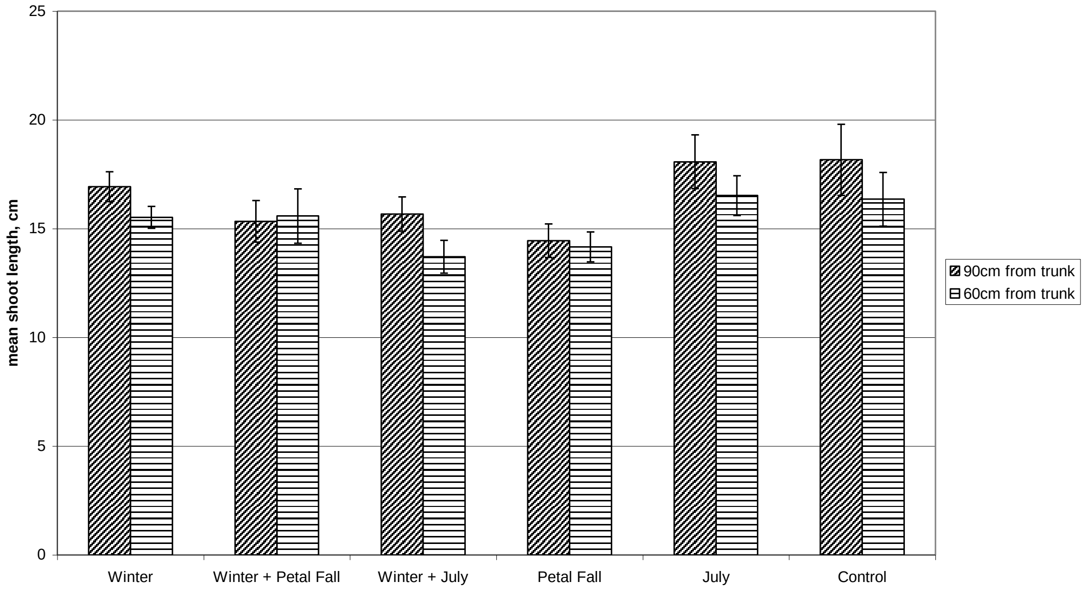


Figure 8. The effect of root pruning on mean extension growth on Cox (mean of 3 years) (for the control columns, 90cm corresponds to blocks A & B and 60cm to blocks C & D).

Results were similar for both Cox and Conference. The single treatment in July had the least effect on shoot elongation. Figure 8 shows that the most severe single treatment on Cox was at petal fall, reducing growth by approximately 18%. Winter plus July gave slightly less growth reduction.

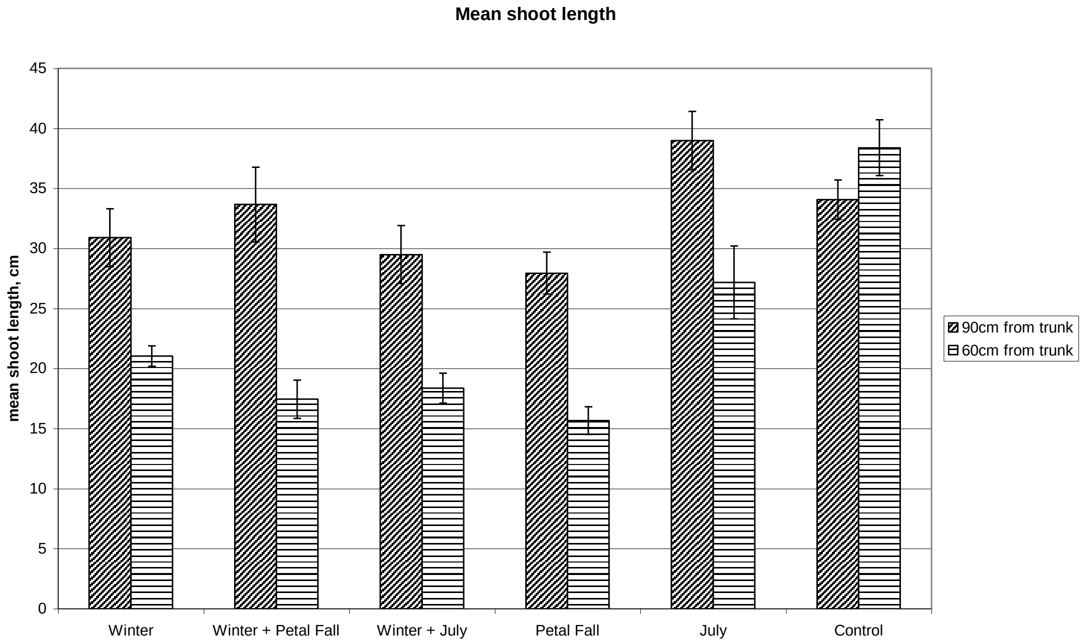


Figure 9. The effect of root pruning on mean extension growth on Conference (mean of 3 years) (for the control columns, 90cm corresponds to blocks A & B and 60cm to blocks C & D).

Figure 9 shows that the most severe single treatment was at petal fall, reducing growth by over 50%. The combined winter plus July treatment resulted in the next greatest reduction in growth and in all cases root pruning at 60cm gave a greater reduction in shoot length than pruning at 90cm.

Figure 10. Petal fall root pruning treatment (60cm) in Conference.

Figure 11. Control root pruning treatment in Conference.

Effects of root pruning on shoot number

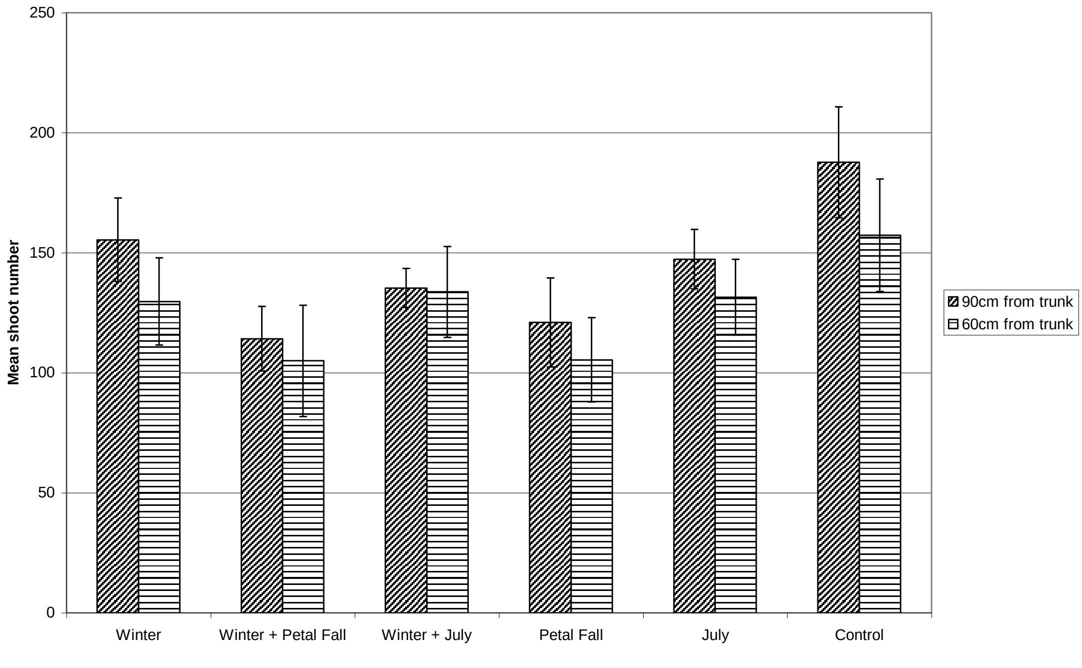


Figure 12. The effect of root pruning on shoot number on Cox When (mean of 3 years) (for the control columns, 90cm corresponds to blocks A & B and 60cm to blocks C & D).

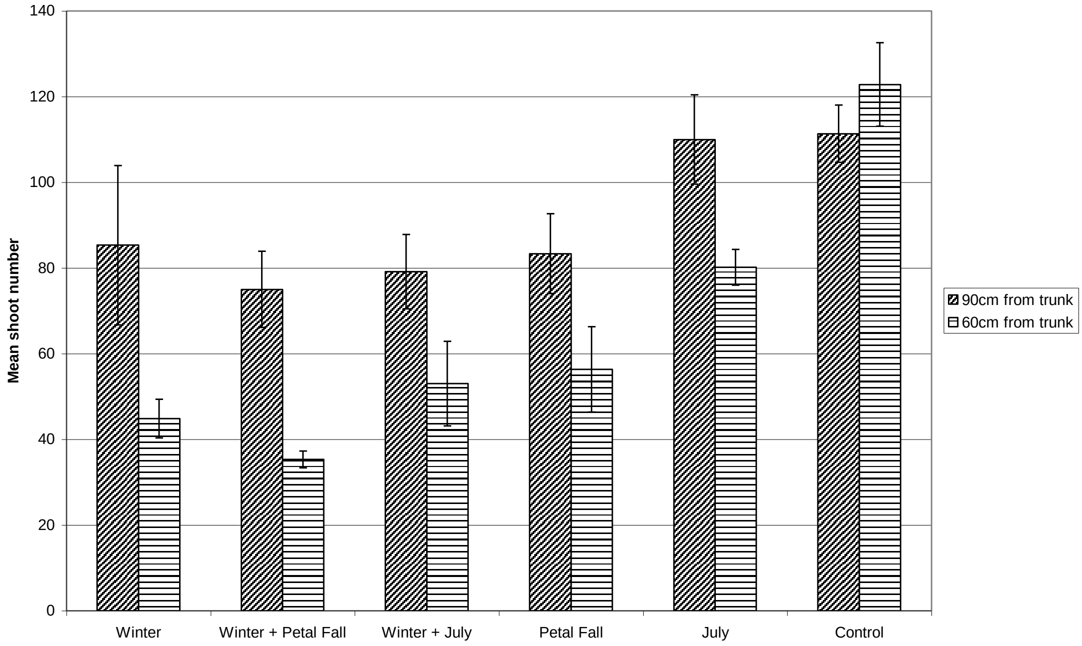


Figure 13. The effect of root pruning on shoot number on Conference (mean of 3 years) (for the control columns, 90cm corresponds to blocks A & B and 60cm to blocks C & D).

Figure 12 shows that the winter plus petal fall treatment had the greatest effect on mean shoot number per tree. Figure 13 shows that a greater reduction in the number of shoots produced occurred when root pruning was carried out at 60cm compared to 90cm, and again shows that the winter plus petal fall treatment had the greatest effect compared with the control.

Effects of root pruning on fruit size

The effects of root pruning treatments on fruit size are shown in the following figures.

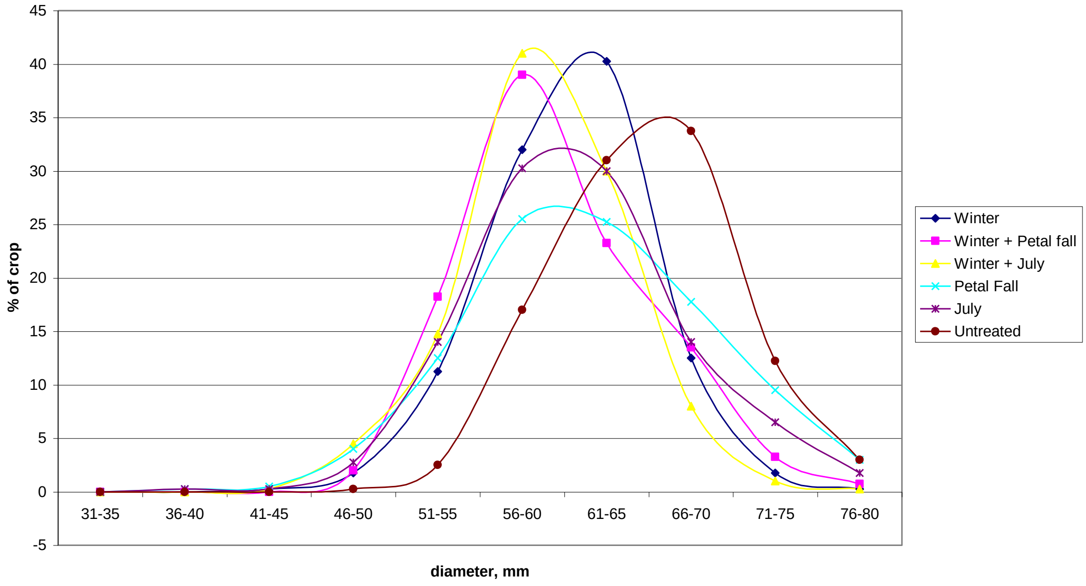


Figure 14. The effect of root pruning treatment at 90 cm from the trunk on fruit size distribution on Cox (mean of 3 years).

It can be seen from Figure 14 that even at a root pruning distance of 90cm from the trunk all treatments had a detrimental effect on fruit size compared with the control, i.e. the curves moved to the left of the control curve. However it was observed that root pruning at 60cm did not give a reduction in fruit size compared with 90cm for the same pruning timing in all cases. Figure 15 shows the average fruit size for each treatment. Although the results for the 60cm and 90cm pruning distances are statistically different for each timing treatment, the results from each end of the control row are also statistically different. The difference in fruit size from each end of the control row indicates that differences in fruit size between 60cm and 90cm pruning distances for a single timing treatment may be due to other positional factors such as soil. Figure 16 illustrates the three year average for petal fall treatment.

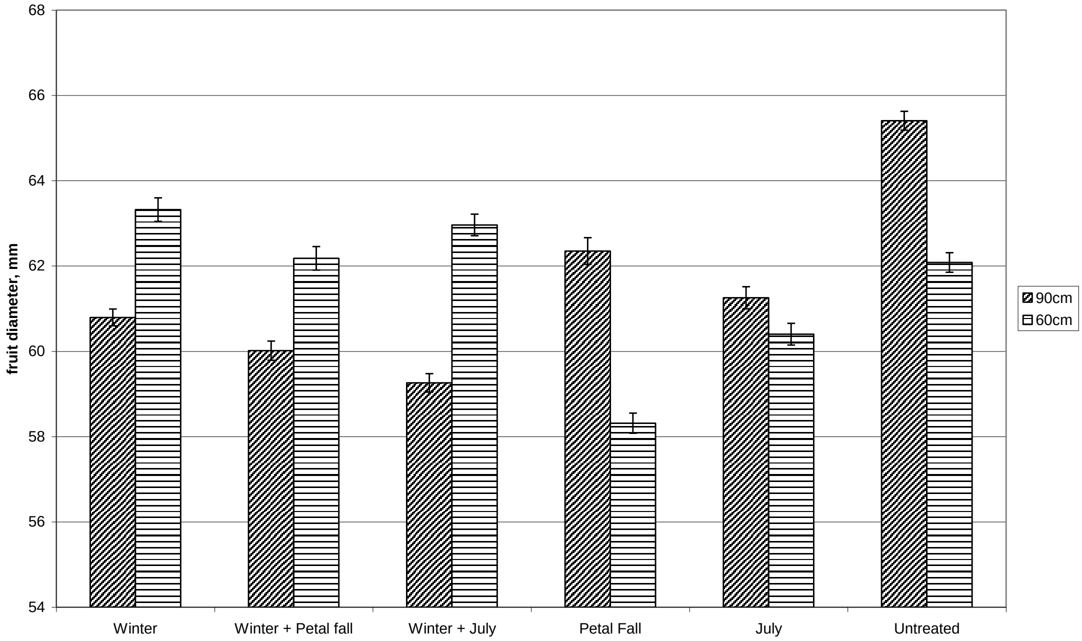


Figure 15. The effect of treatment on mean fruit size on Cox – 3-year mean.

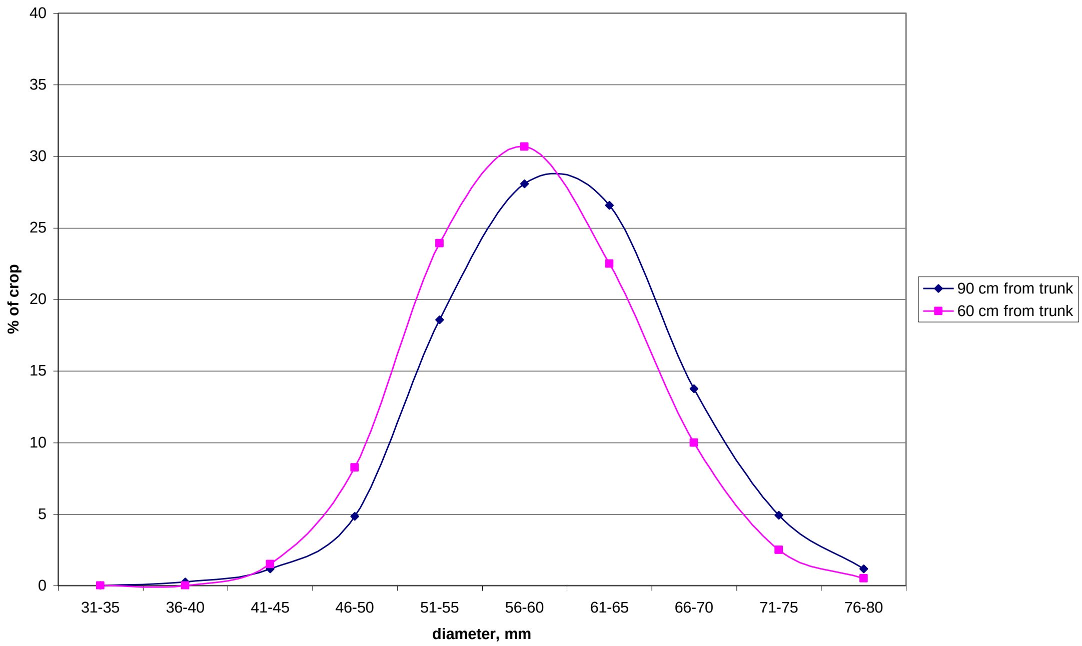


Figure 16. The effect of root pruning distance on fruit size distribution on Cox (petal fall treatment, 3 year average).

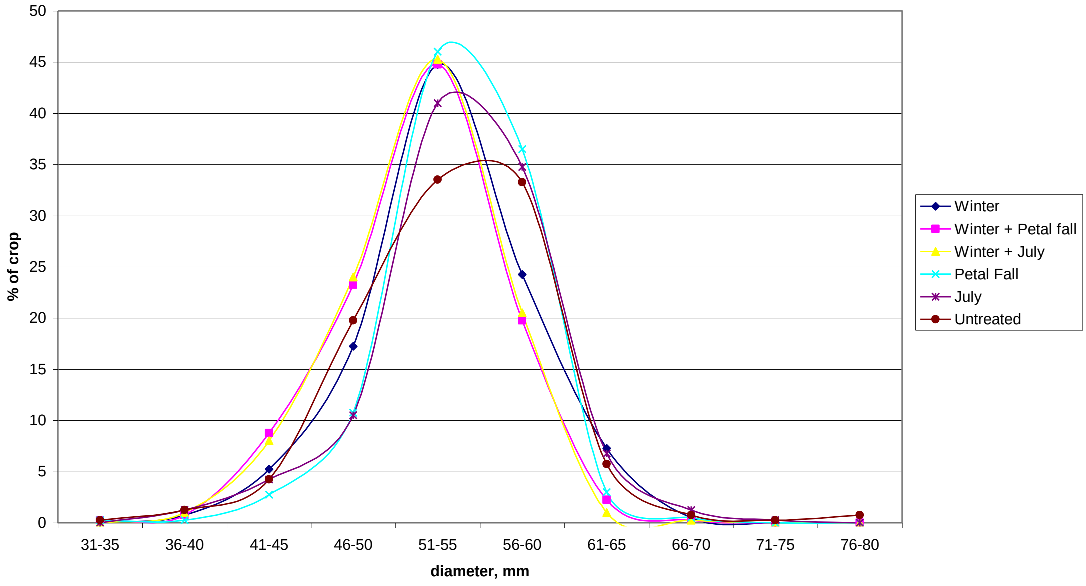


Figure 17. The effect of root pruning treatment at 90cm from the trunk on fruit size distribution on Conference (3 year average).

It can be seen from Figure 17 and 18 that none of the root pruning treatments had a positive effect on fruit size. Treatments carried out at 60cm caused a greater reduction in fruit size than treatments carried out at 90cm with the 60cm winter plus July treatment causing the greatest reduction in fruit size. No effect on average fruit size (Figure 18) was observed for any of the single (winter, petal fall or July) 90cm treatments compared to the control. Whereas the combined winter plus petal fall and winter plus July treatments at 90cm caused a significant reduction in fruit size. For each of the timings of treatment application it could also be seen that root pruning at 60cm reduced the average fruit size compared with the 90cm treatment.

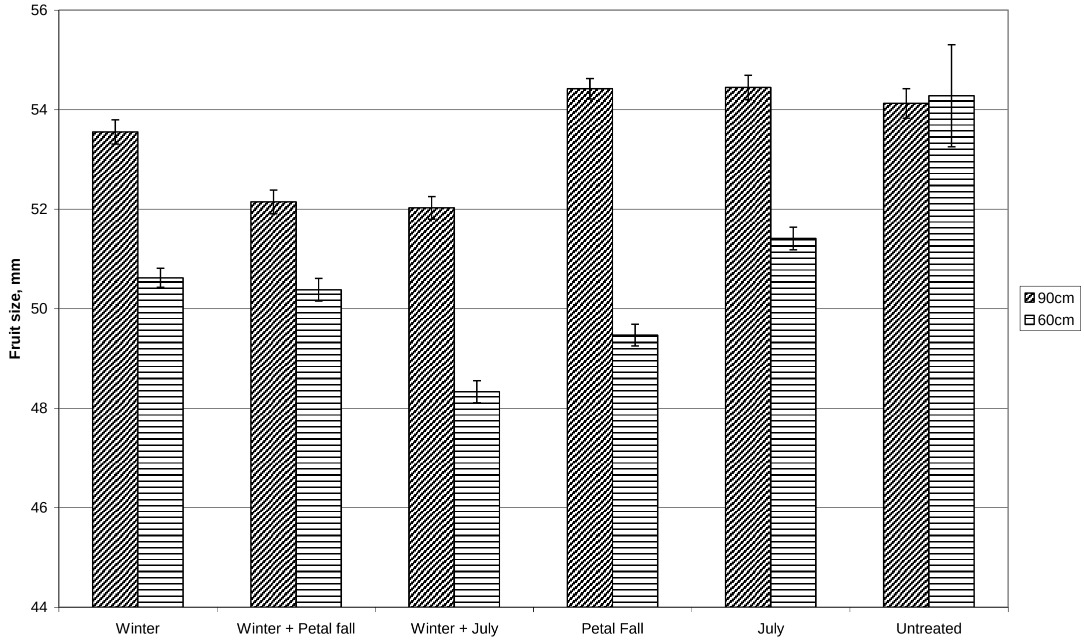


Figure 18. The effect of treatment on mean fruit size in Conference in 2006.

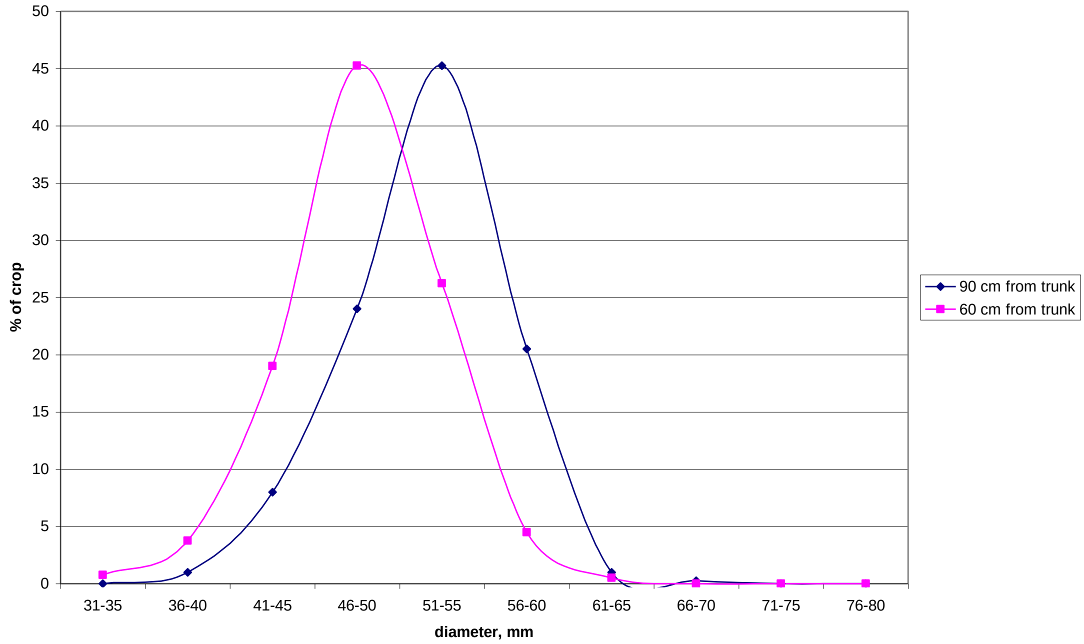


Figure 19. The effect of root pruning distance on fruit size distribution in Conference (winter and July treatment) in 2006.

It can be seen from Figure 19 that the root pruning treatment conducted at 60cm resulted in an overall depression in fruit size to a greater extent than the root pruning treatment conducted at 90cm in 2006. This was the case for each treatment timing, unlike in the case of Cox.

Effects of root pruning on fruit number in 2006

The results for fruit number in 2006 indicated that in Cox where root pruning occurred during the winter fruit numbers were reduced for the 60cm pruning treatment compared with the 90cm pruning treatment. There was no effect on fruit numbers for any timing treatment at 90cm compared with the control and no effect on the single petal fall and July treatments compared to the control. See Figure 20. It was noticed in the orchard that there was a band of trees that appeared to have become biennial bearing which ran through the 60cm end of the winter, winter plus petal fall and winter plus July treatments. Whether this was a direct result of pruning timing and distance combined with the 2005 heavy crop or a change in soil properties is not possible to say. In the case of Conference, Figure 21, no significant change in fruit number was observed in 2006, apart from in the petal fall and July 60cm treatments which resulted in a decrease compared to the control.

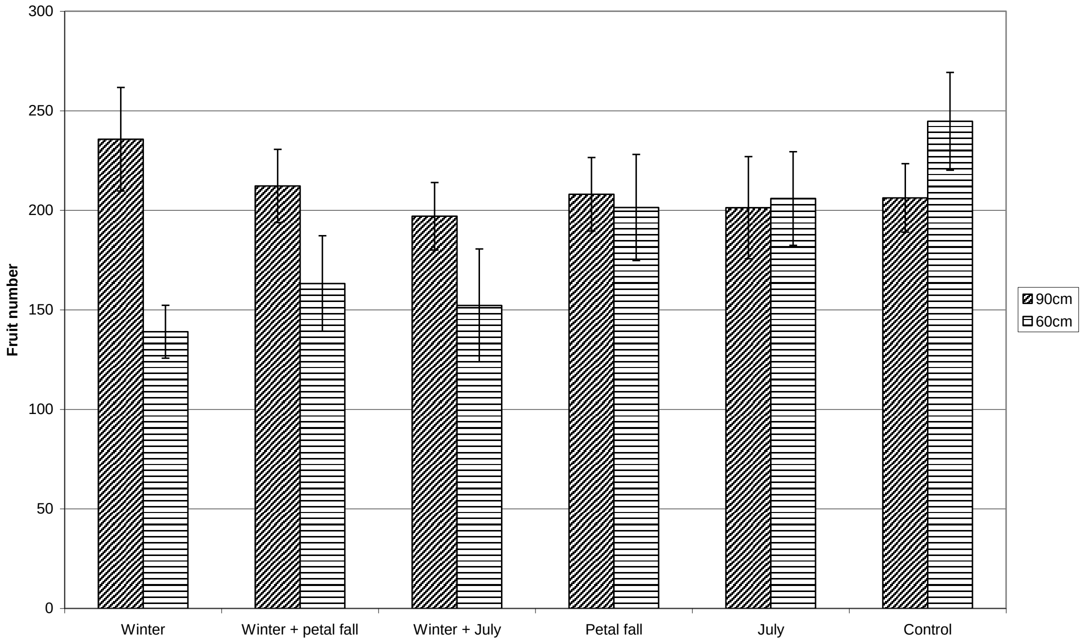


Figure 20. The effect of root pruning treatment on fruit number in Cox in 2006 (for the control columns, 90cm corresponds to blocks A & B and 60cm corresponds to blocks C & D).

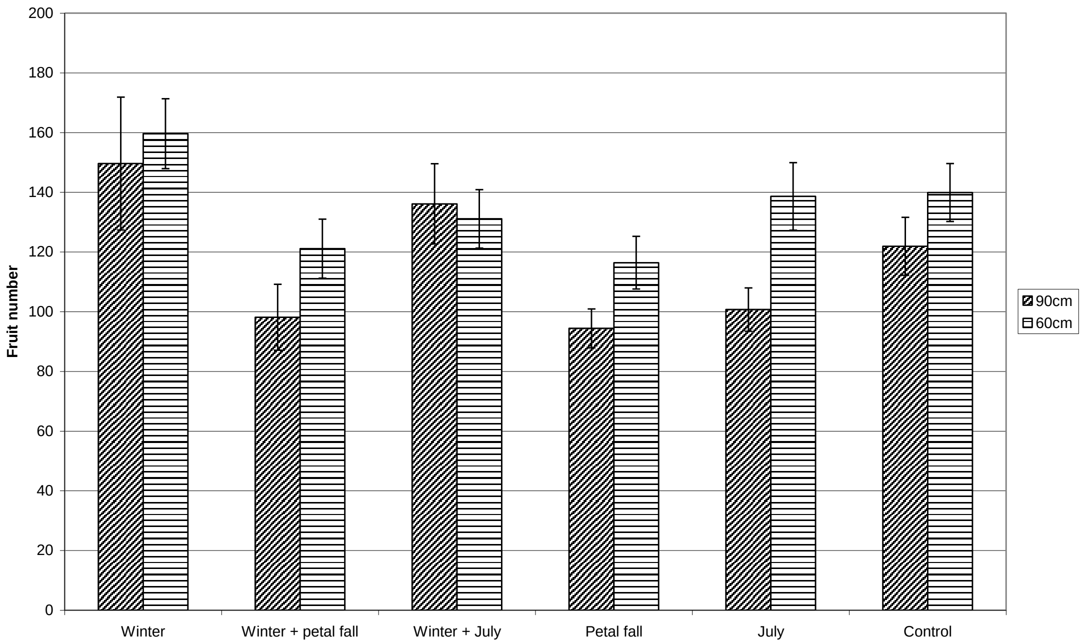


Figure 21. The effect of root pruning treatment on fruit number in Conference in 2006 (for the control columns, 90cm corresponds to blocks A & B and 60cm corresponds to blocks C & D).

It is known that crop load has an effect on fruit size and one technique for achieving a specific crop size is by manipulation of crop load, i.e. thinning. The greater the number of fruit, the smaller the fruit will be, providing other factors remain constant. It can be seen from Figure 20 that all treatment timings at a distance of 90cm in Cox had a similar crop load and thus any effect on crop size can be assumed to be due to treatment. When assessing results from other treatments, the relative crop load had to be taken into account.

Effects of root pruning on flower number

The Cox flower buds were visually assessed at full bloom on the 29th April 2004, 25th April 2005 and 4th May 2006 using a score of 1 to 10, where 1 represented no flower buds on the branch and 10 represented the maximum potential number of flower buds along a branch for good fruit set. The mean results for all three years are shown in Table 1.

Table 1. Cox flower bud score.

	2004		2005		2006	
Root Pruning Treatment	90 cm	60 cm	90 cm	60 cm	90 cm	60 cm
Dormant period	8	6	8	9	9.5	8.5
Petal fall	8	8	8	8	9.5	9.5
Early July	9	8.5	9	8	10	9
Dormant period and Petal Fall	8.5	8.5	8	8	9.5	9.5
Dormant period and Early July	9	8.5	9	8	9.5	9.5
Control, unpruned (equivalent distance positions)	9	8.5	9	8	9.5	9.5

The Conference flower buds were visually assessed at full bloom on the 19th April 2004, 20th April 2005 and 27th April 2006 using a score of 1 to 10, where 1 represented no flower buds on the branch and 10 represented the maximum potential flower buds along a branch. The results are shown in Table 2.

Table 2. Conference flower bud score.

	2004		2005		2006	
Root Pruning Treatment	90 cm	60 cm	90 cm	60 cm	90 cm	60 cm
Dormant period	8	8	8	8	7.5	8.5
Petal fall	8	8	8	8	7.5	8.5
Early July	8	8	8	8	7.5	8.5
Dormant period and Petal Fall	8	8	8	8	7.5	7.5
Dormant period and Early July	8	8	8	8	7.5	8
Control, unpruned (equivalent distance positions)	8	8	8	8	7.5	7.5

It can be seen that in the case of Cox that all trees had a reasonable number of flower buds, although there was a little variability between treatments, both timing of application of root pruning and distance of root pruning application. The results show that more flower buds were present in 2006 than in 2004 or 2005. However it was also observed that there was a difference in flower number between different ends of the control row in 2004 and 2005 indicating differences due to environmental conditions, the observed differences between treatments were also relatively small with all scores being either 8 or 9.

In the case of Conference no differences were observed in flower number between any of the treatments in 2004 and 2005, but in 2006 although there was little difference between treatment timings there was a slight difference due to treatment distance with slightly more flowers in the 60cm treatments.

Effects of root pruning on fruit set

The Cox fruit set was visually assessed at the 15mm fruitlet stage using a score of 1 to 10, where 1 represented no fruit set and 10 represented the maximum potential fruit set. The results are shown in Table 3.

Table 3. Cox fruit set score.

	2004		2005		2006	
Root Pruning Treatment	90 cm	60 cm	90 cm	60 cm	90 cm	60 cm
Dormant period	8	7	8	8	8	8
Petal fall	8	8	8	7	8	8
Early July	8	8	8	8	8	8
Dormant period and Petal Fall	8	8	8	8	8	8
Dormant period and Early July	9	8	9	8	9	8
Control, unpruned (equivalent distance positions)	8	8	9	8	8	8

The Conference fruit set was visually assessed at the 15mm fruitlet stage using a score of 1 to 10, where 1 represented no fruit set and 10 represented the maximum potential fruit set. The results are shown in Table 4.

Table 4. Conference fruit set score.

	2004		2005		2006	
Root Pruning Treatment	90 cm	60 cm	90 cm	60 cm	90 cm	60 cm
Dormant period	8	8	8	8	8	8
Petal fall	8	8	8	8	8	8
Early July	8	8	8	8	8	8
Dormant period and Petal Fall	8	8	8	8	8	8
Dormant period and Early July	8	8	8	8	8	8
Control, unpruned (equivalent distance positions)	8	8	8.5	8	8	8

Cox showed a good fruit set with very little variation between treatments over the three year period and Conference also showed good fruit set with no variation between treatments in 2004 and 2006 and only slight variation in 2005.

Effects of root pruning on soil analysis in 2006

Removal of nutrients from the soil solution around a plant can be due to nutrient uptake by the plant or by leaching caused by excessive irrigation or rainfall. The following results will therefore have been affected by plant uptake and rainfall prior to soil sampling and this must therefore be taken into account when interpreting the results.

The following graphs for 2006 express nutrient levels in the soil of each treatment as a percentage of the nutrient levels of the control where no root pruning occurred. These results have been presented as an average of the two distances (60cm and 90cm) from the trunk of the tree so that effects due to timing rather than distance can be highlighted. The graphs also show a line indicating optimum level based on historical data for the crop, relative to the control treatment.

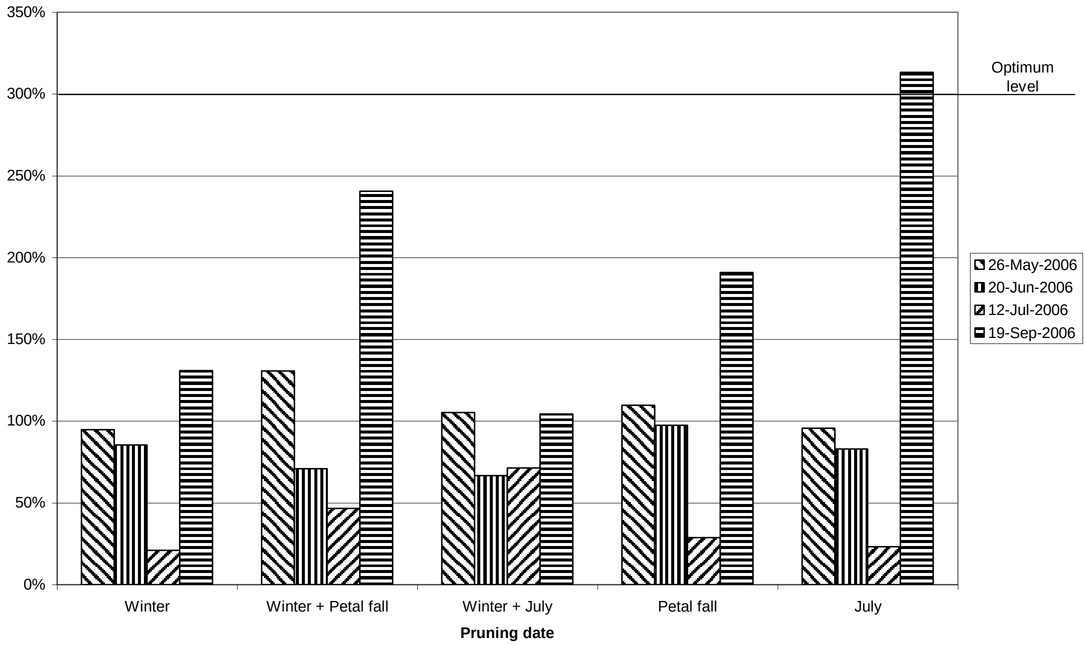


Figure 22. Potassium levels in the soil solution under Cox expressed as a percentage of the control treatment in 2006.

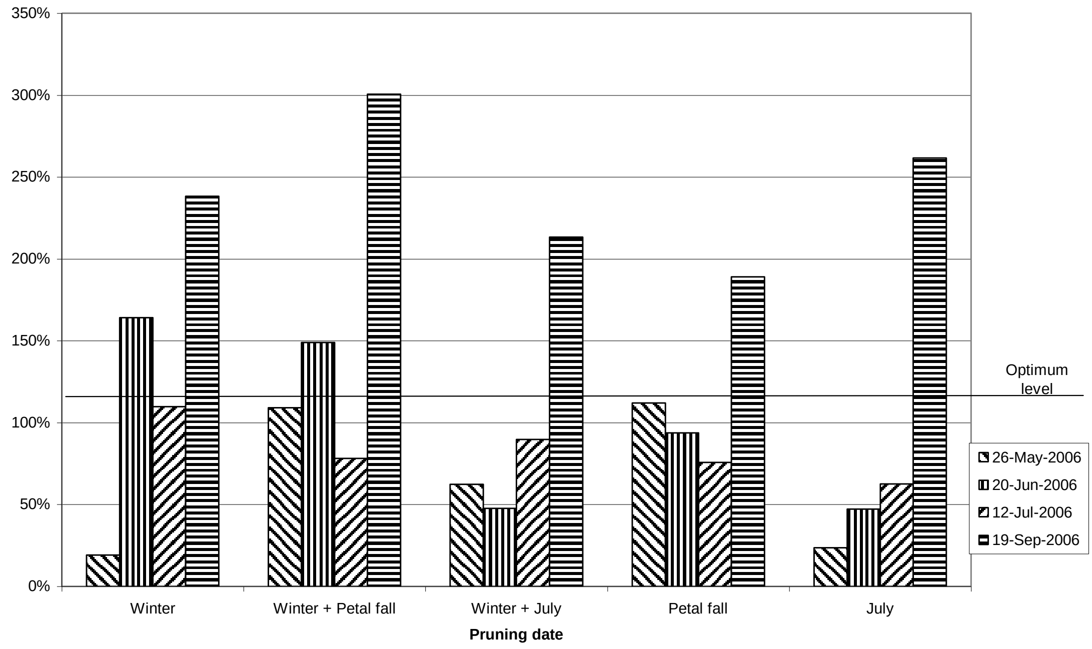


Figure 23. Calcium levels in the soil solution under Cox expressed as a percentage of the control treatment in 2006.

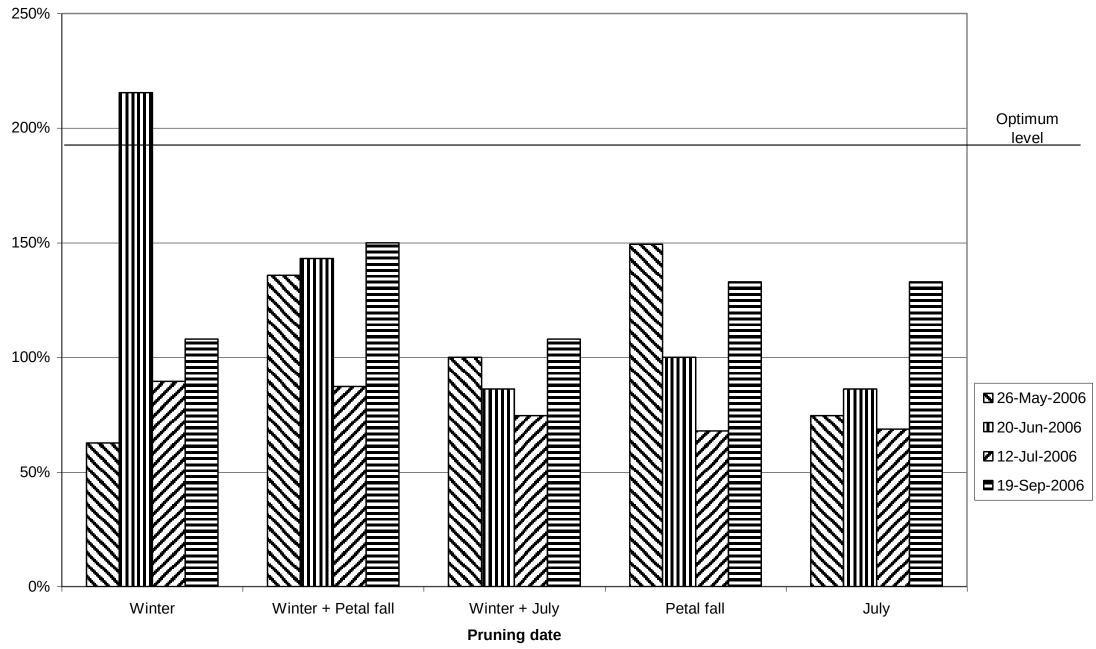


Figure 24. Magnesium levels in the soil solution under Cox expressed as a percentage of the control treatment in 2006.

It can be seen in Figure 22 that in May and June potassium in the soil solution was similar to the control at approximately 30% of the recommended level. Levels tended to fall again in July and increase in September, but only in the July treatment did levels reach recommended rates. However sap analysis confirms that sufficient potassium was received by the plant via foliar feeding. Figure 23 shows large variations within and between treatments.

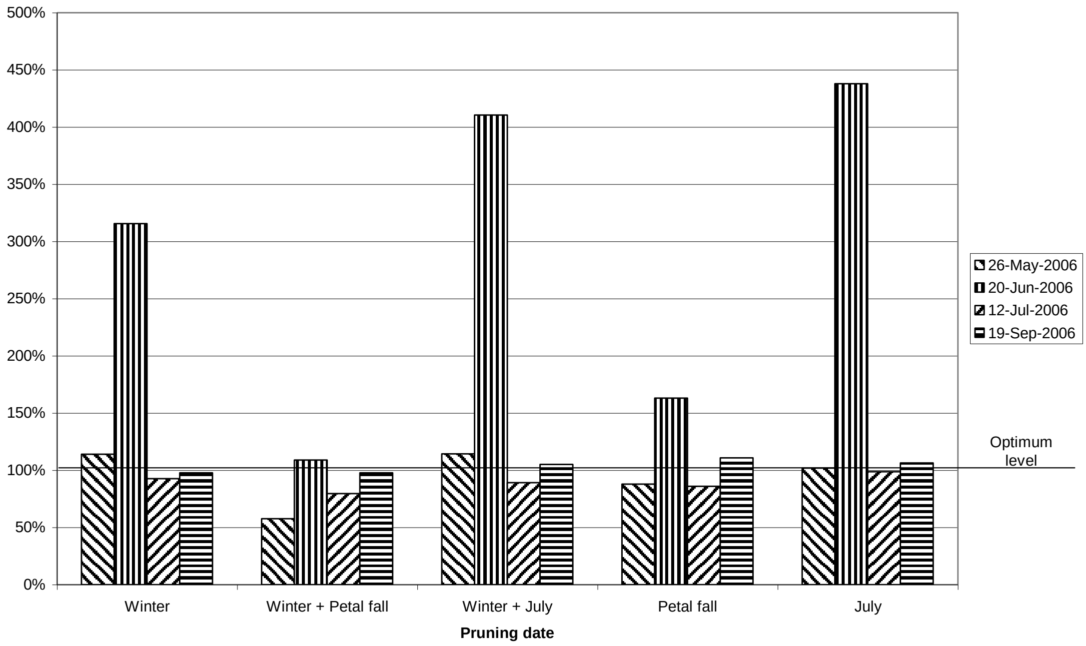


Figure 25. Potassium levels in the soil solution under Conference expressed as a percentage of the control treatment in 2006.

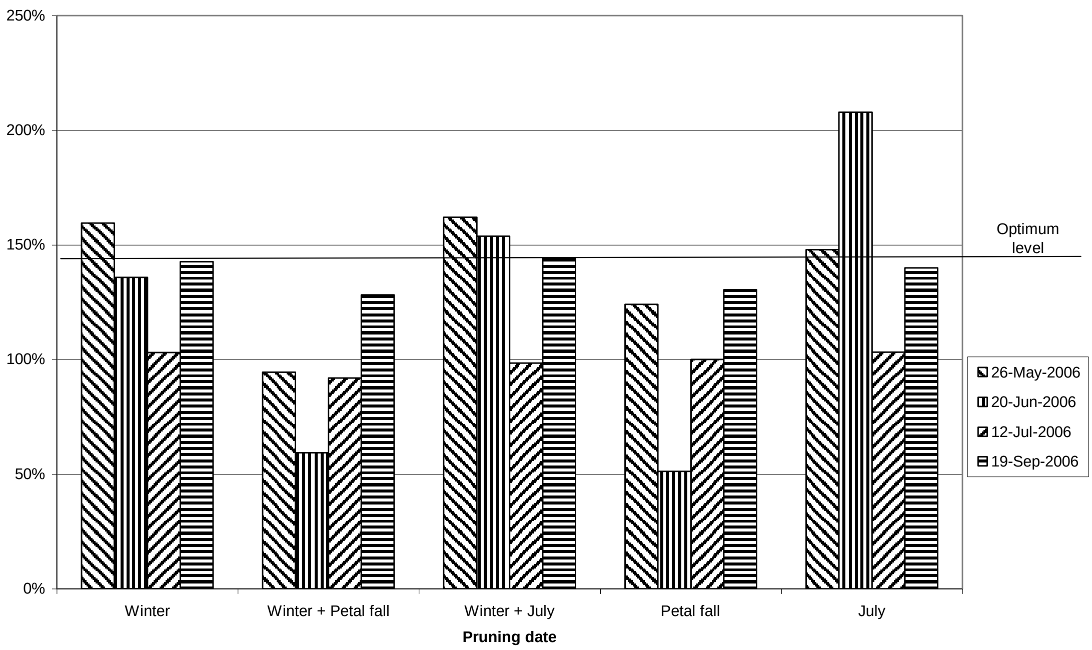


Figure 26. Calcium levels in the soil solution under Conference expressed as a percentage of the control treatment in 2006.

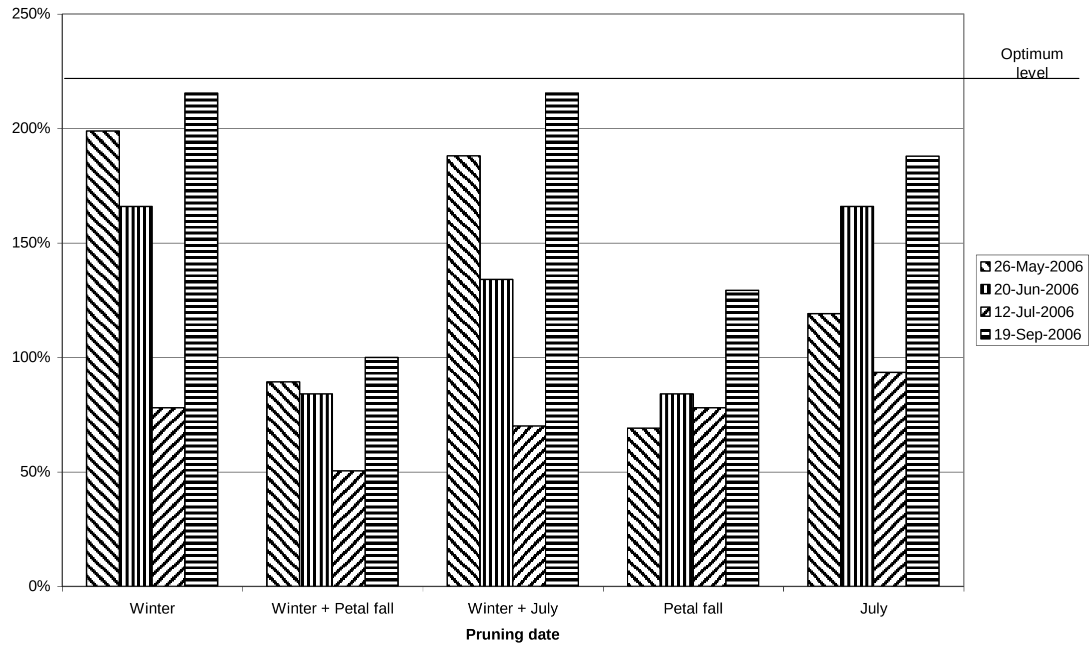


Figure 27. Magnesium levels in the soil solution under Conference expressed as a percentage of the control treatment in 2006.

Figures 25-27 show differences in potassium, calcium and magnesium in the soil under Conference in 2006. Figure 25 shows potassium levels in the soil to be approximately equal to that of the control for the May, June and September samples. In all cases except for the winter plus petal fall treatment the 20th June sample is 3 to 4.5 times greater than the control. Figure 26 shows that the level of calcium was less than in the control for all sample dates in the petal fall and winter plus petal fall treatments. Figure 27 shows the petal fall and winter plus petal fall treatments to have lower levels of magnesium than the other treatment timings. However in all cases levels were below optimal.

Soil moisture in 2006

The following figures show soil moisture at different depths over time during the 2006 season. Sensor 1 corresponds to 10cm below the soil surface, sensor 2 to 20cm, sensor 3 to30cm, sensor 4 to 50cm and sensor 5 to 90cm.

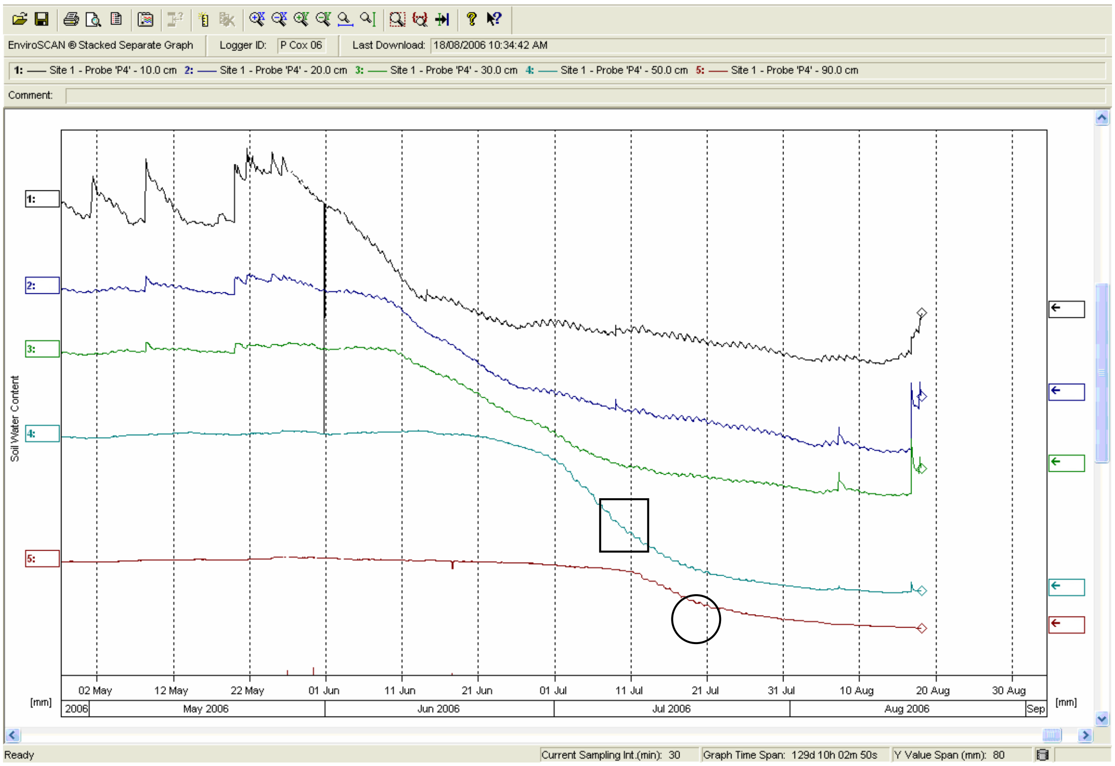


Figure 28. Enviroscan data for winter + petal fall treatment at 60cm in Cox in 2006.

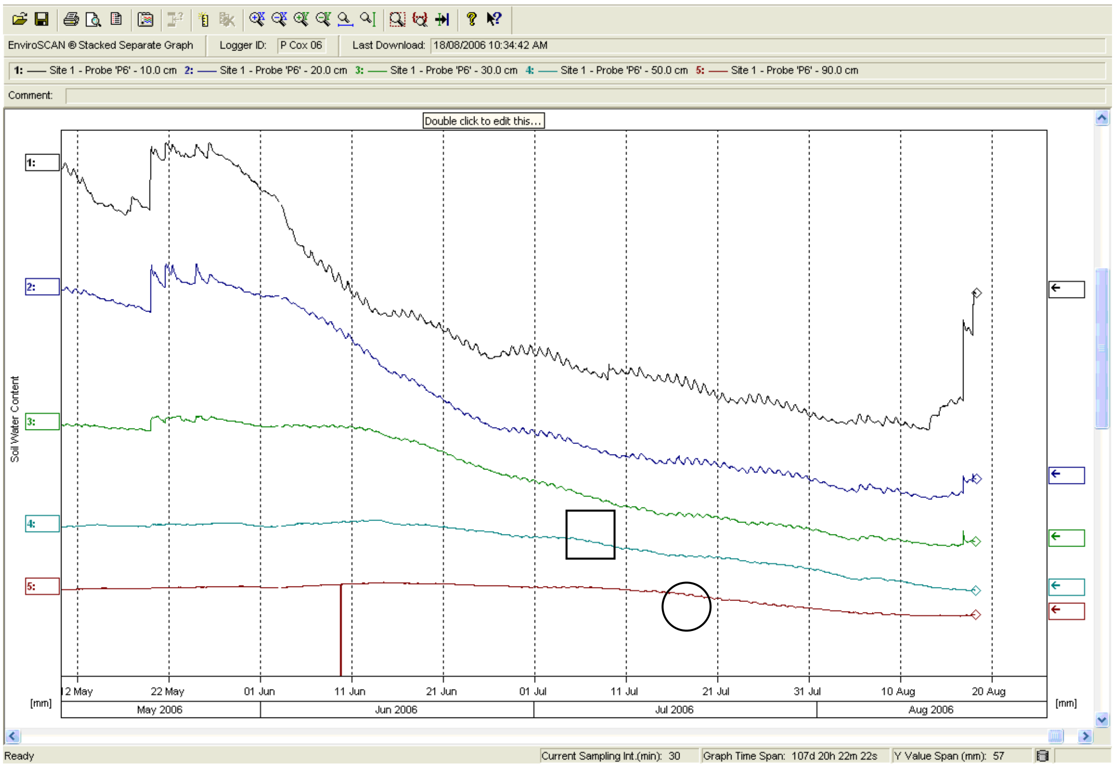


Figure 29. Enviroscan data for control in Cox in 2006.

It can be seen from the circle over the line for probe 5 (90cm) in the winter plus petal fall treatment, Figure 28, that there is a stepped decline for the line on the graph at this position. The same portion of the control graph, Figure 29, shows less of a decline with virtually no stepping. Stepping on the graph indicates that water is actively taken up, therefore the stepping from the winter plus petal fall treatment at this position in the soil profile indicates that the remaining roots were 'working harder and deeper' to extract water. This can also be seen in the figures for sensor 4 at a position of 50cm in the soil profile, indicated by a square. Water was being actively extracted for the winter plus petal fall treatment and a more stable situation was observed in the control with no water extraction at this depth. These 2006 graphs show the same results as in 2005.

The graphs for the pears, Figures 30 and 31, show more stepping on the winter plus petal fall treatment compared with the control (oval on the figures) indicating that more active water extraction occurred at depth in the treatment than in the control. A rainfall event is also indicated on these figures (oblong) which shows that in the control, Figure 31, the soil profile was wetted to a depth of 50cm, whereas in the winter plus petal fall treatment, Figure 30, the soil profile was only wetted to a depth of 20cm indicating that the soil was drier in the treatment at depth than in the control.

Where the root volume was affected by root pruning the trees' water requirements had to be drawn from deeper in the soil. This requires more energy and would in turn have an effect on other processes in the tree such as vegetative growth and fruit size.

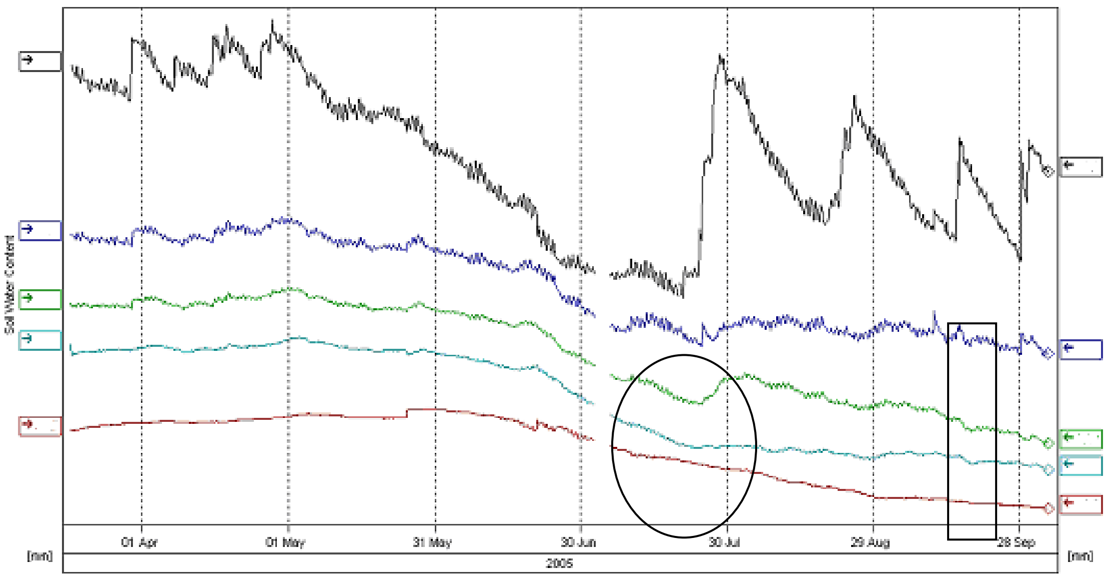


Figure 30. Enviroscan data for winter + petal fall treatment at 60cm in Conference, 2005.

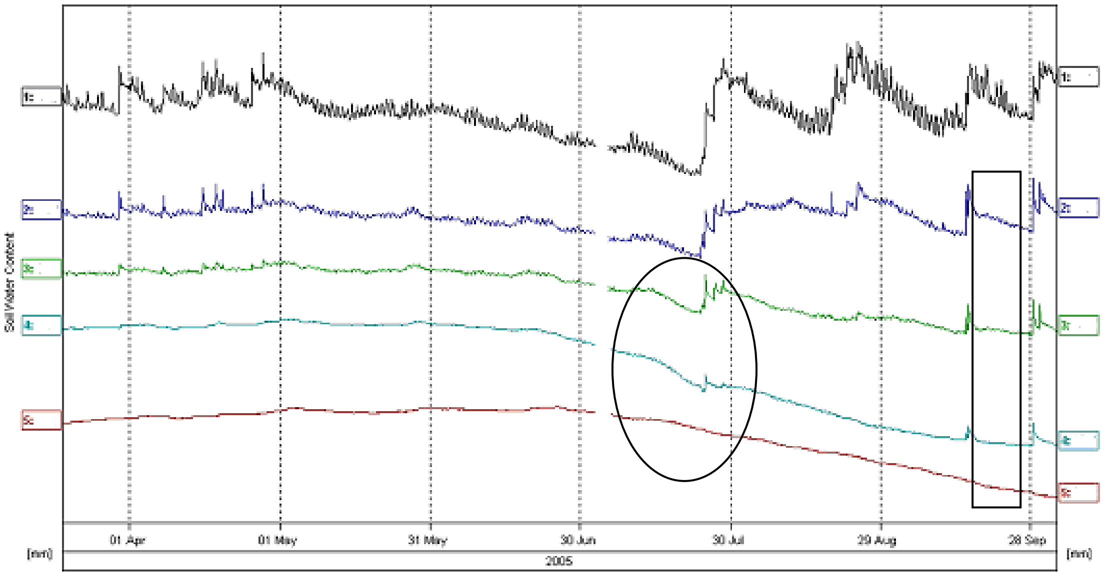


Figure 31. Enviroscan data for control in Conference, 2005.

Effects of root pruning on sap analysis

The following graphs express the 2006 nutrient levels in the sap of leaves of each treatment as a percentage of the nutrient levels of the control where no root pruning occurred. The results have been presented as an average of the two distances (60cm and 90cm) from the trunk of the tree so that effects due to timing rather than distance can be highlighted. The graphs also show a line indicating optimum level based on historical data for the crop, relative to the control treatment.

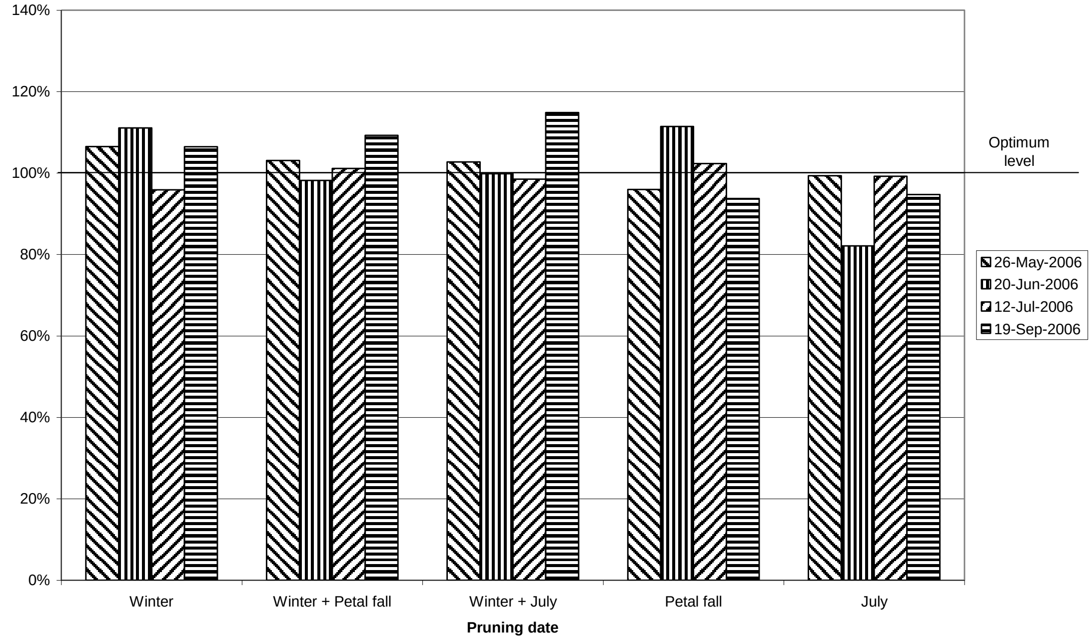


Figure 32. Potassium levels in the sap of Cox leaves expressed as a percentage of the control treatment in 2006.

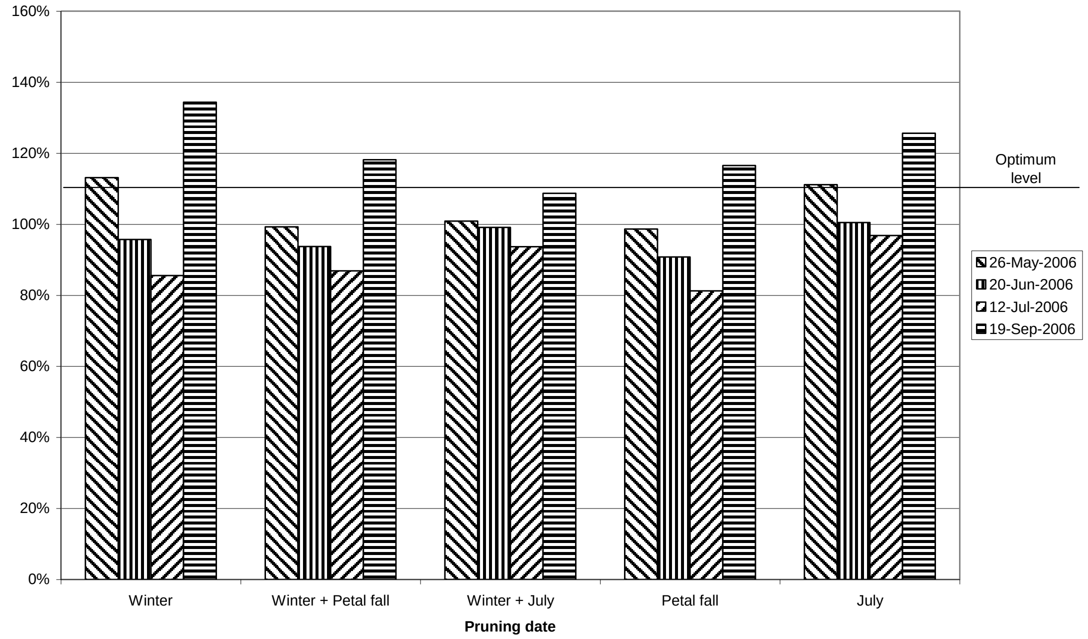


Figure 33. Calcium levels in the sap of Cox leaves expressed as a percentage of the control treatment in 2006.

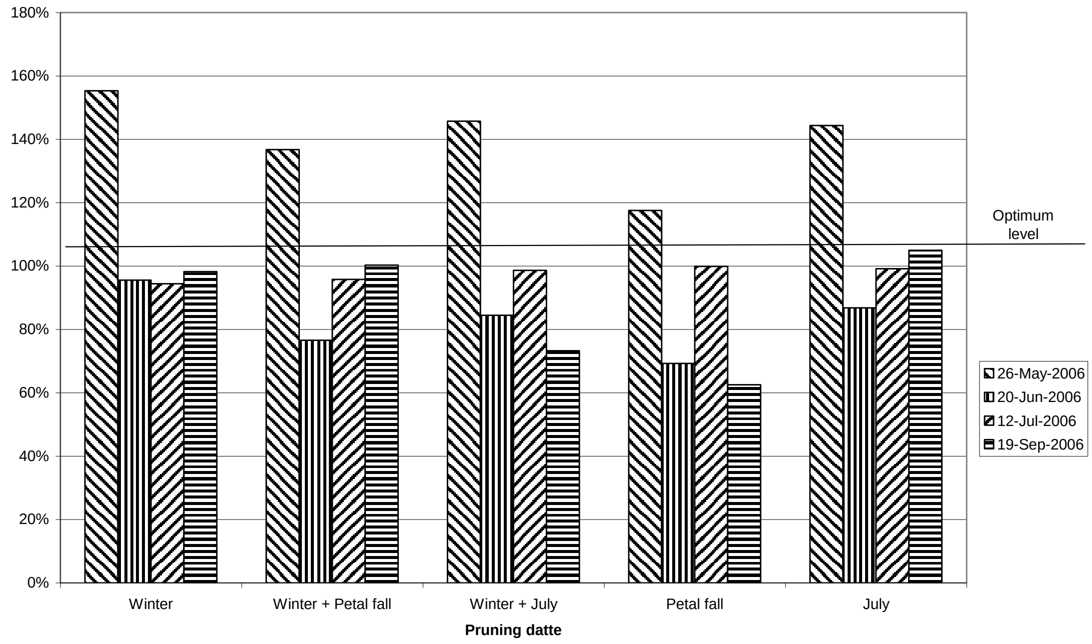


Figure 34. Magnesium levels in the sap of Cox leaves expressed as a percentage of the control treatment in 2006.

It can be seen from Figures 32-34 that root pruning affected nutrient uptake in Cox in 2006. Figure 32 shows that where winter root pruning was carried out there was little effect on potassium levels, but post blossom root pruning may reduce potassium uptake and only in the case of the July root pruning treatment was potassium in leaf sap continuously lower than that of the control. Figure 33 shows that calcium concentration in each treatment fell during the season and then increased at the September sampling date. This is to be expected as calcium accumulates in tissues when growth slows at the end of the season.

Figure 34 shows in each case magnesium uptake was greater than that of the control on 26th May 2006 and then fell to levels below that of the control except for the September sample for the July treatment.

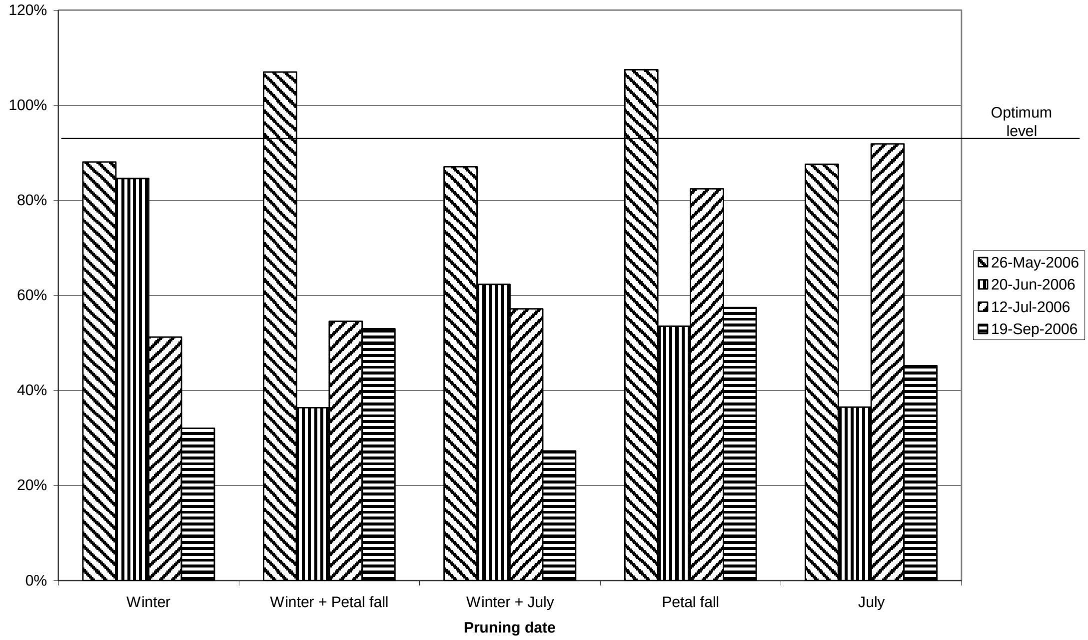


Figure 35. Potassium levels in the sap of Conference leaves expressed as a percentage of the control treatment in 2006.

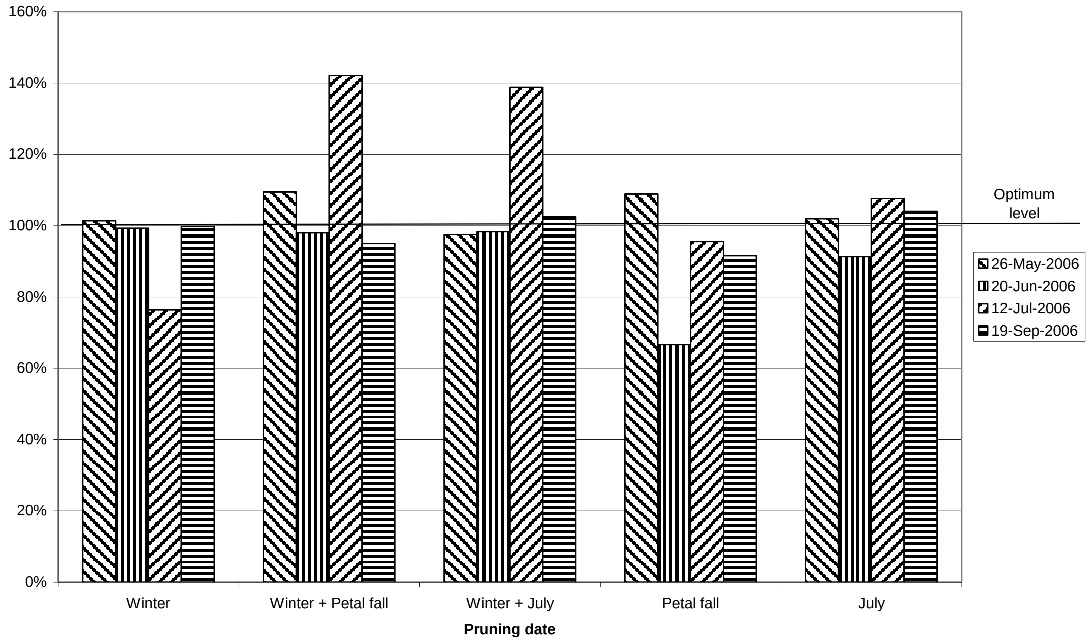


Figure 36. Calcium levels in the sap of Conference leaves expressed as a percentage of the control treatment in 2006.

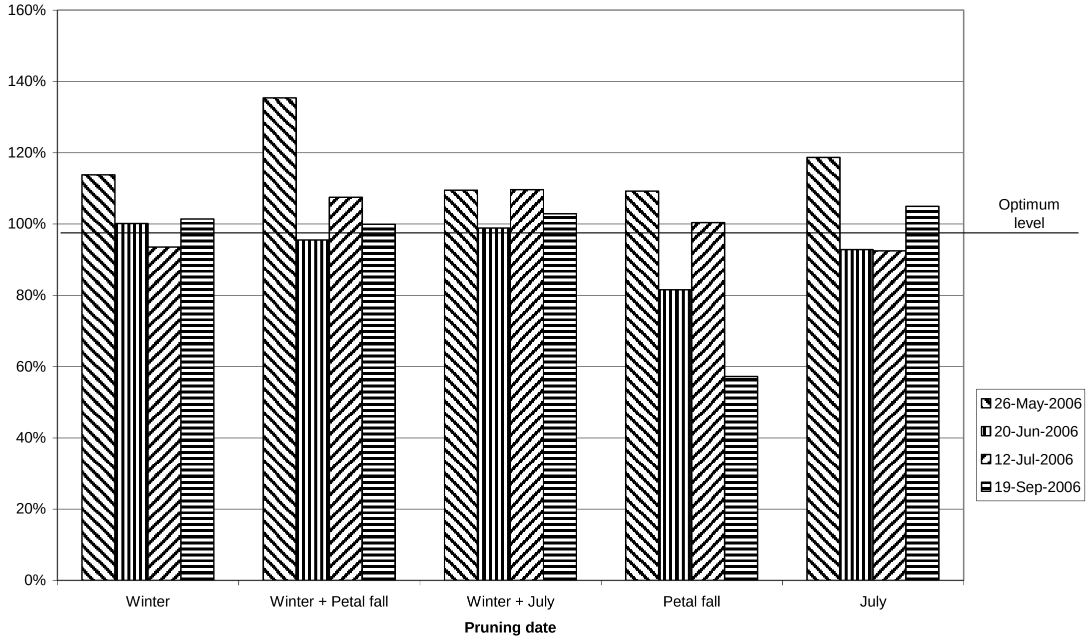


Figure 37. Magnesium levels in the sap of Conference leaves expressed as a percentage of the control treatment in 2006.

Figures 35-37 also show root pruning to have had an effect of nutrient uptake in Conference in 2006. Figure 35 shows a general depression in potassium uptake in pruning treatments compared with the control. Relative to the control potassium levels were only greater at the initial sampling on 26th May for the winter plus petal fall and petal fall treatments. Figure 36 shows calcium levels to be generally sufficient and in excess on 12th July for the winter plus petal fall and winter plus July treatments. Figure 37 shows an initial increase in magnesium levels compared with the control, which is most pronounced in the winter plus petal fall treatment. Levels then generally remained around that of the control but in the petal fall treatment the level fell at the last sampling date as it did in 2005.

Effects of root pruning on leaf analysis in 2006

Dry tissue analysis of leaves was carried out on two dates during each year of the trial. The first sampling was at blossom and the second after growth ceased.

The following graphs express the 2006 nutrient levels in the leaf for each treatment as a percentage of the nutrient levels of the control where no root pruning occurred. The results have been presented as an average of the two distances (60cm and 90cm) from the trunk of the tree so that effects due to timing rather than distance can be highlighted. The graphs also show a line indicating optimum level based on historical data for the crop, relative to the control treatment.

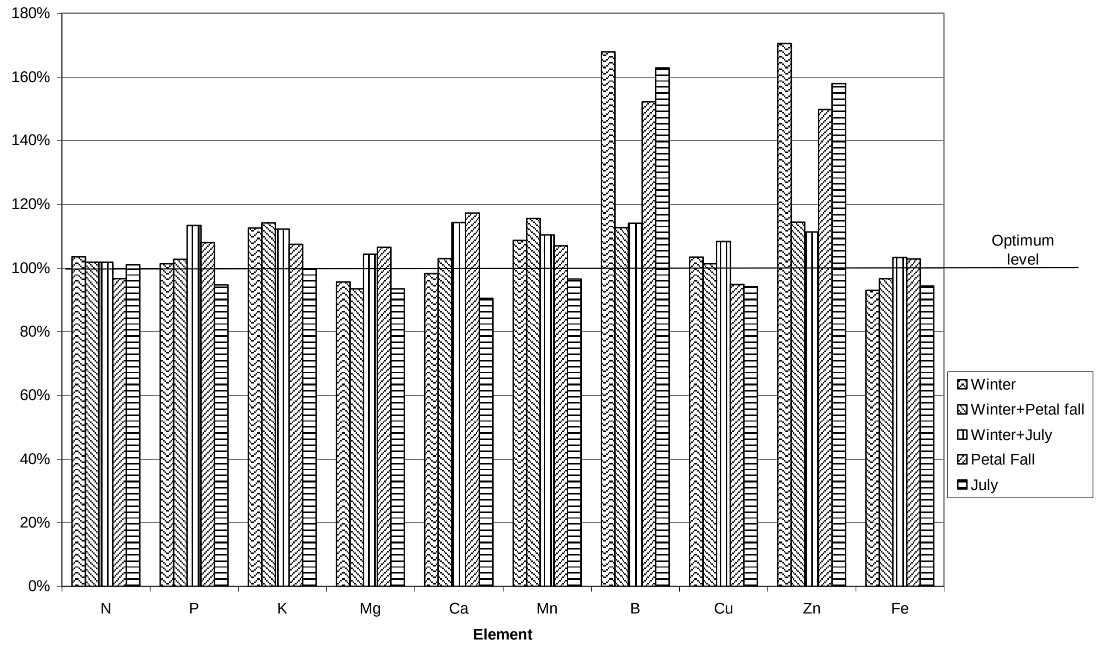


Figure 38. Nutrient levels in the leaves of Cox on 3rd May 2006 expressed as a percentage of the control treatment.

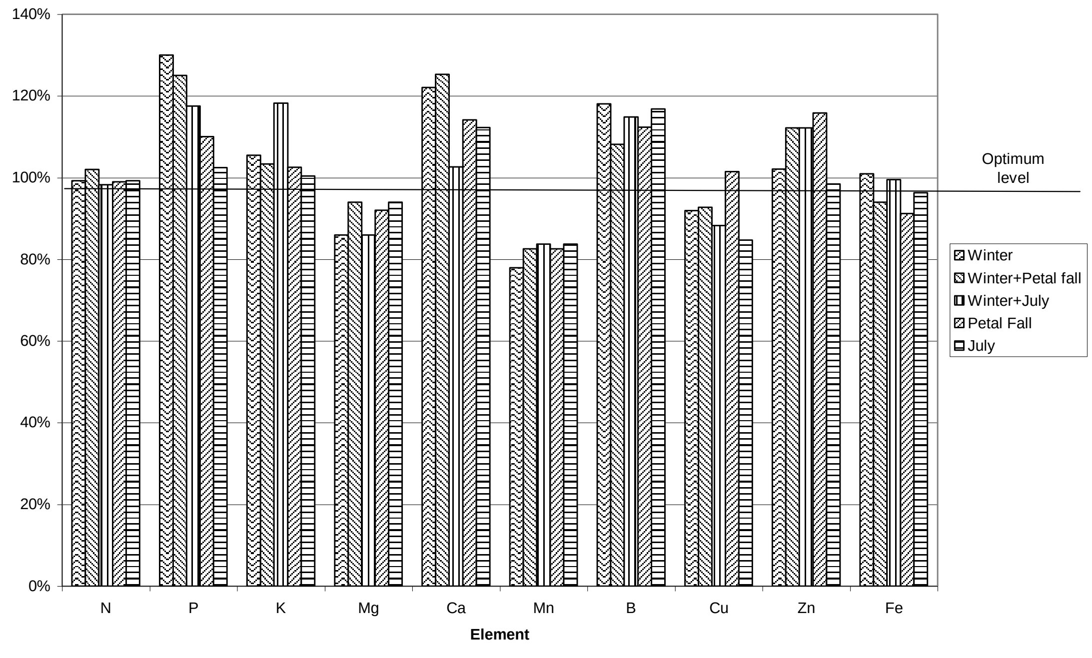


Figure 39. Nutrient levels in the leaves of Cox on 8th September 2006 expressed as a percentage of the control treatment.

It can be seen in Figure 38 that the least quantity of nitrogen had accumulated in the Cox leaves in the petal fall treatment. Boron and zinc levels appeared to respond positively to each of the treatments, however it was subsequently confirmed that the orchard had received a spray of boron and zinc the day before sampling. It can be seen in Figure 39 that magnesium and manganese levels responded negatively to each of the treatments and nitrogen, phosphorous, potassium, calcium and boron levels responded positively to each of the treatments.

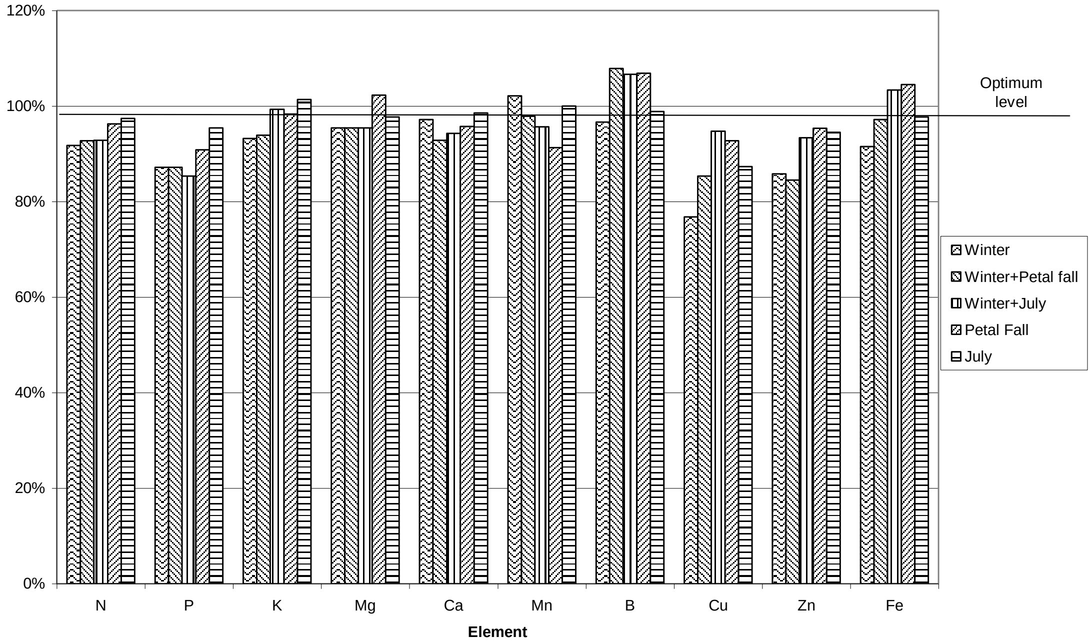


Figure 40. Nutrient levels in the leaves of Conference on 3rd May 2006 expressed as a percentage of the control treatment.

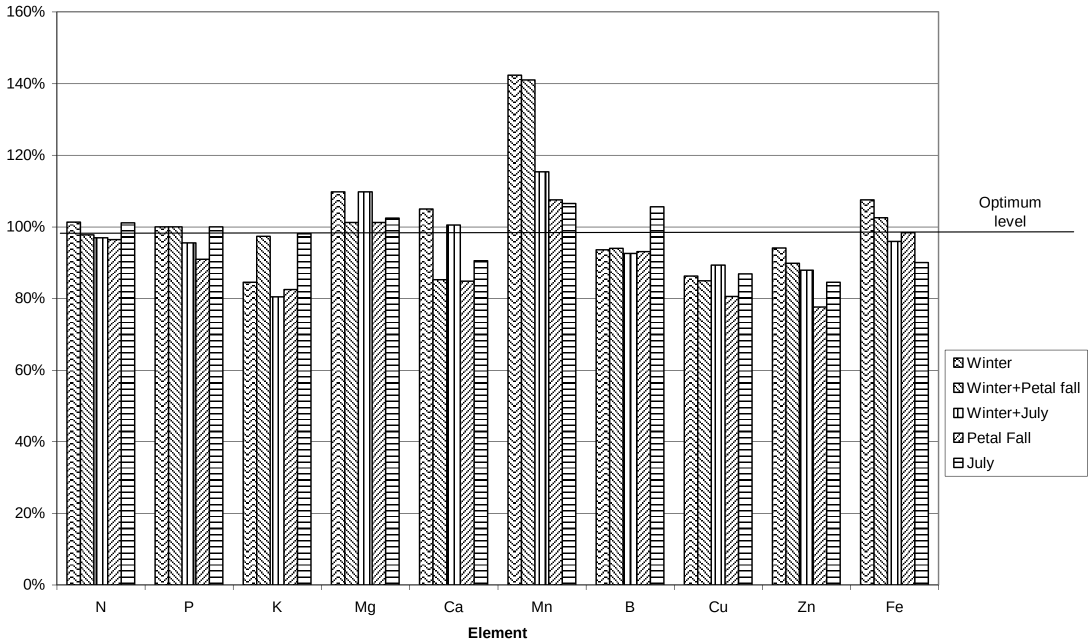


Figure 41. Nutrient levels in the leaves of Conference on 8th September 2006 expressed as a percentage of the control treatment.

It can be seen in Figure 40 that nitrogen, phosphorous, calcium, copper and zinc levels were reduced in the leaves of Conference for all root pruning treatments. Conversely magnesium and manganese levels were elevated in the leaves of Conference for all root pruning treatments. It can be seen in Figure 41 that on the 8th September 2006 manganese levels were elevated and copper and zinc levels were reduced in all treatments.

Effects of root pruning on fruit analysis in 2006

Fruit analysis was carried out approximately one to two weeks prior to harvest using industry standard sampling and analytical techniques. The following graphs express nutrient levels in the fruit for each treatment as a percentage of the nutrient levels of the control where no root pruning occurred. The results have been presented as an average of the two distances (60cm and 90cm) from the trunk of the tree so that effects due to timing rather than distance can be highlighted. The graphs also show a line indicating optimum level based on historical data for the crop, relative to the control treatment.

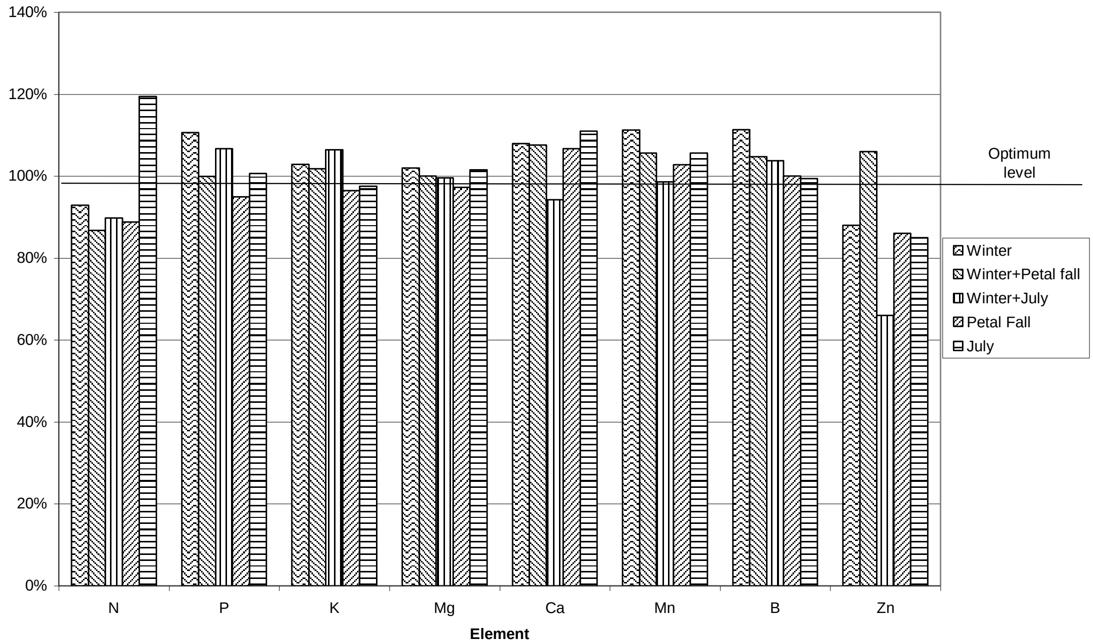


Figure 42. Nutrient levels in the fruit of Cox 8th September 2006 expressed as a percentage of the control treatment.

Figure 42 shows that magnesium levels were largely unaffected by any of the root pruning treatments. The winter plus July treatment shows the biggest increase in potassium levels relative to the control and the largest reduction in calcium levels relative to the control.

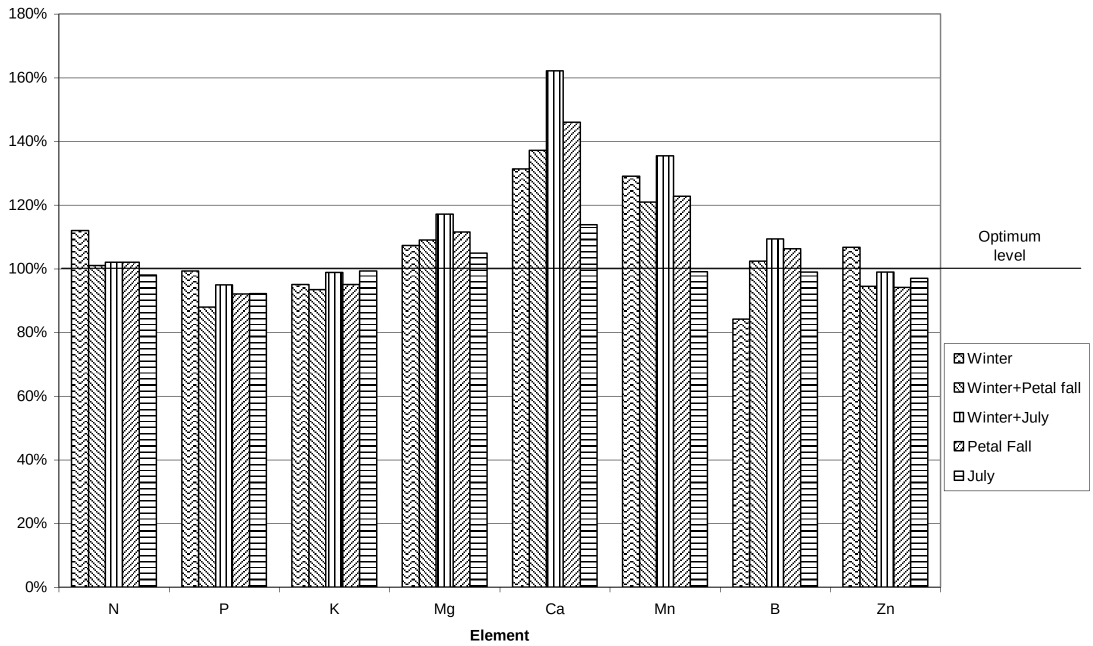


Figure 43. Nutrient levels in the fruit of Conference on 8th September 2006 expressed as a percentage of the control treatment.

It can be seen from Figure 43 that the levels of magnesium, calcium and manganese increased relative to the control whereas phosphorous and potassium levels were depressed in all treatments.

Effects of root pruning on pest and disease status

There was no noticeable difference in the pest and disease status between treatments for either the Cox or the Conference.

Mean results of root pruning over the three year period

Results are presented graphically and discussed in the Discussion and Conclusion sections.

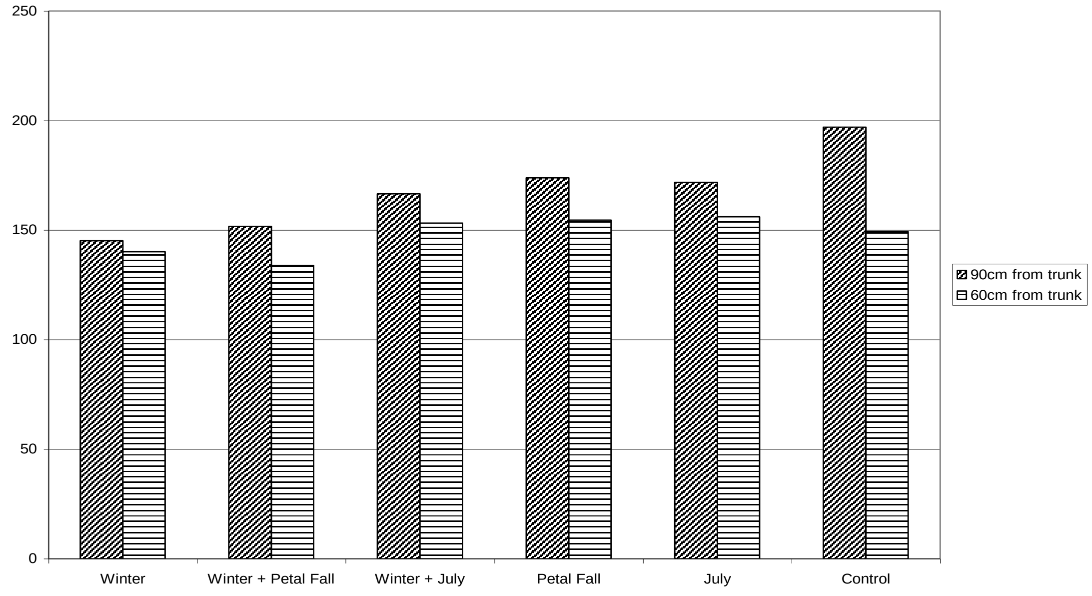


Figure 44. The effect of root pruning on mean shoot number (3 year average) in Cox.

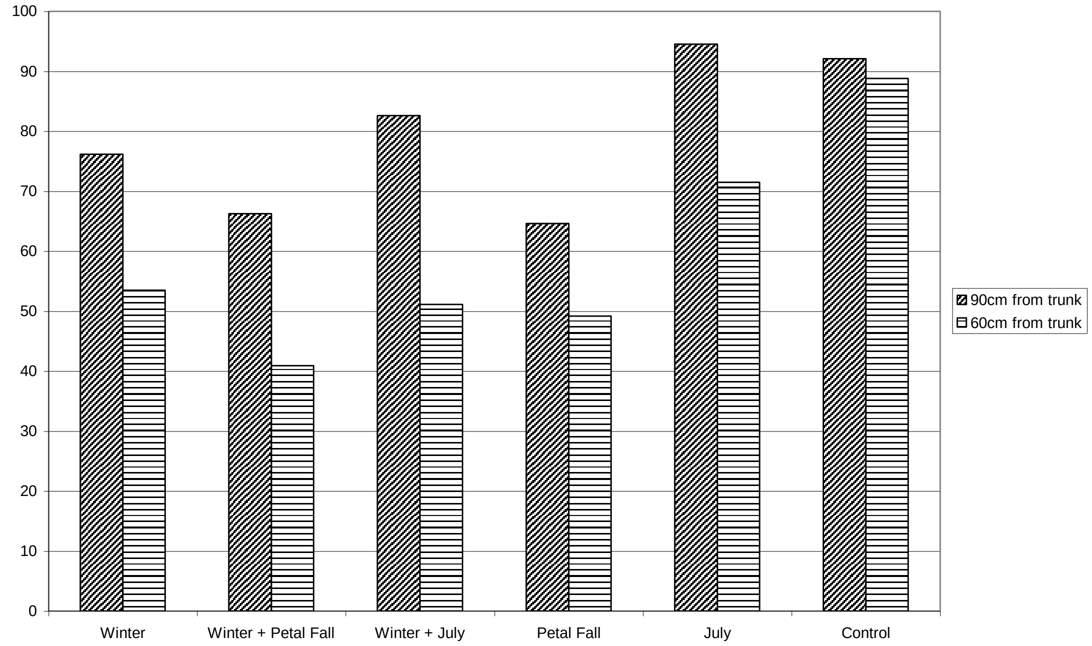


Figure 45. The effect of root pruning on mean shoot number (3 year average) in Conference.

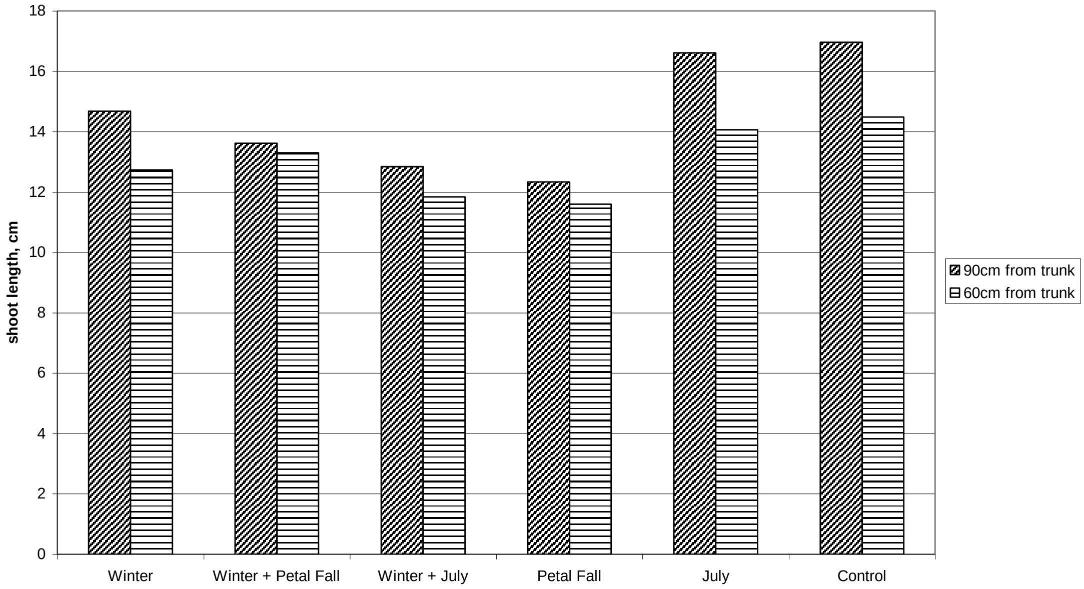


Figure 46. The effect of root pruning on mean shoot length (3 year average) in Cox.

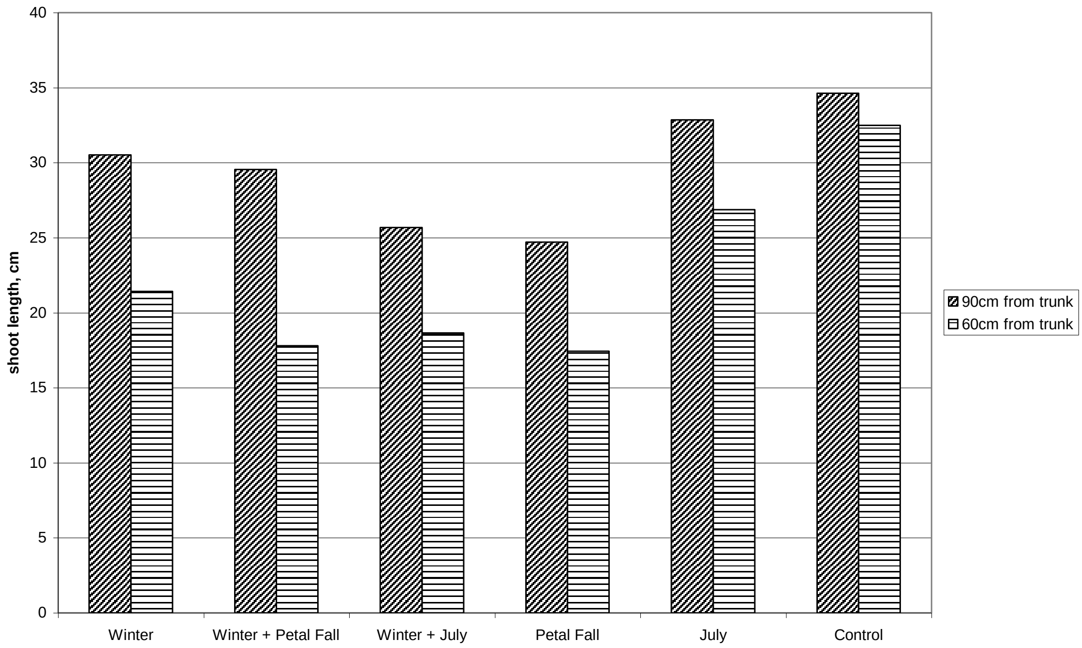


Figure 47. The effect of root pruning on mean shoot length (3 year average) in Conference.

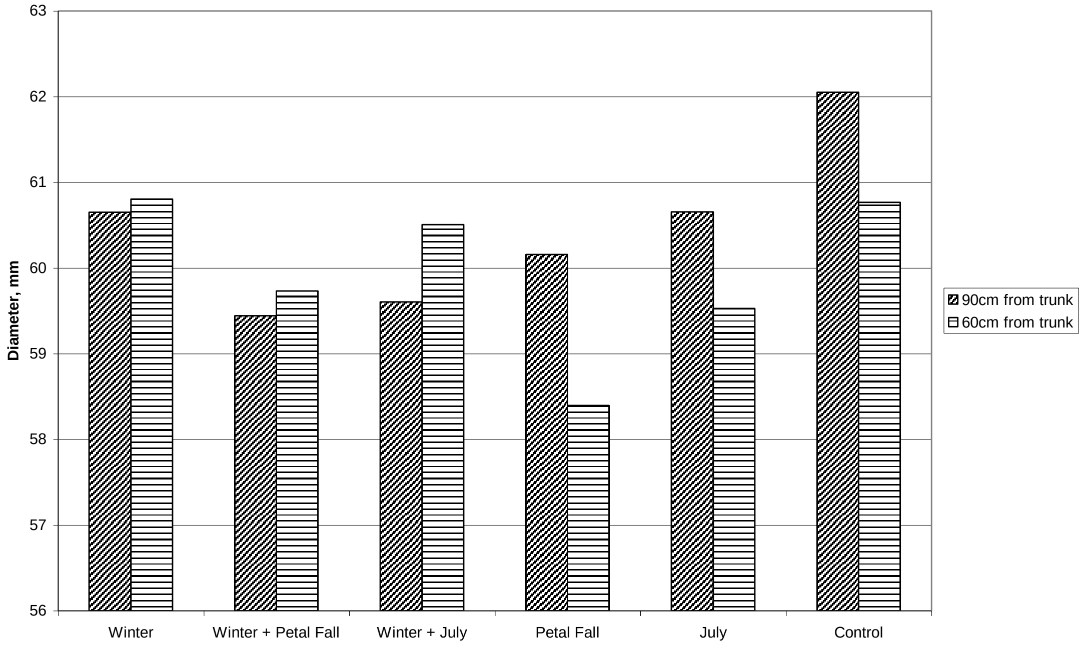


Figure 48. The effect of root pruning on mean fruit size (3 year average) in Cox.

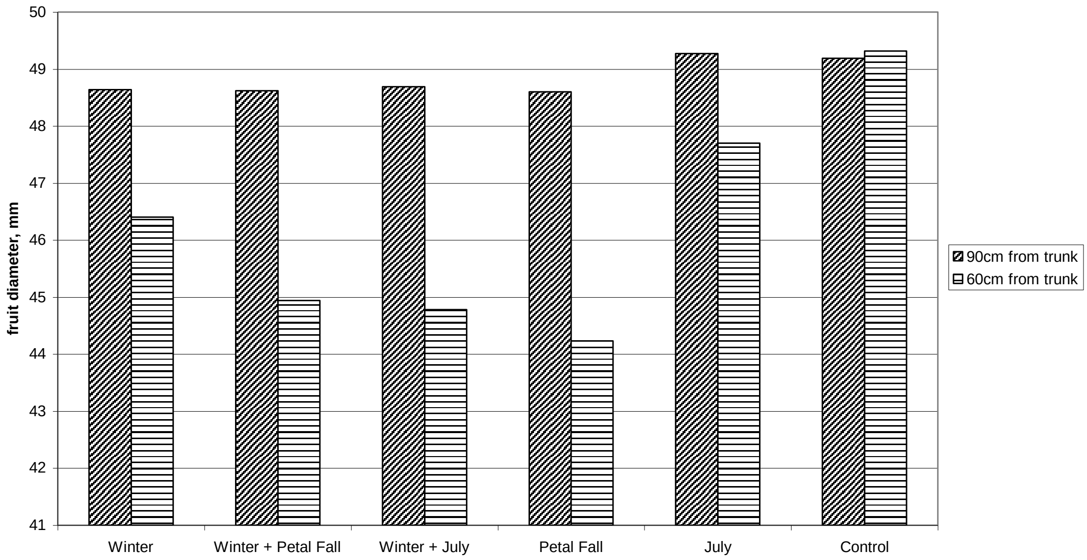


Figure 49. The effect of root pruning on mean fruit size (3 year average) in Conference.

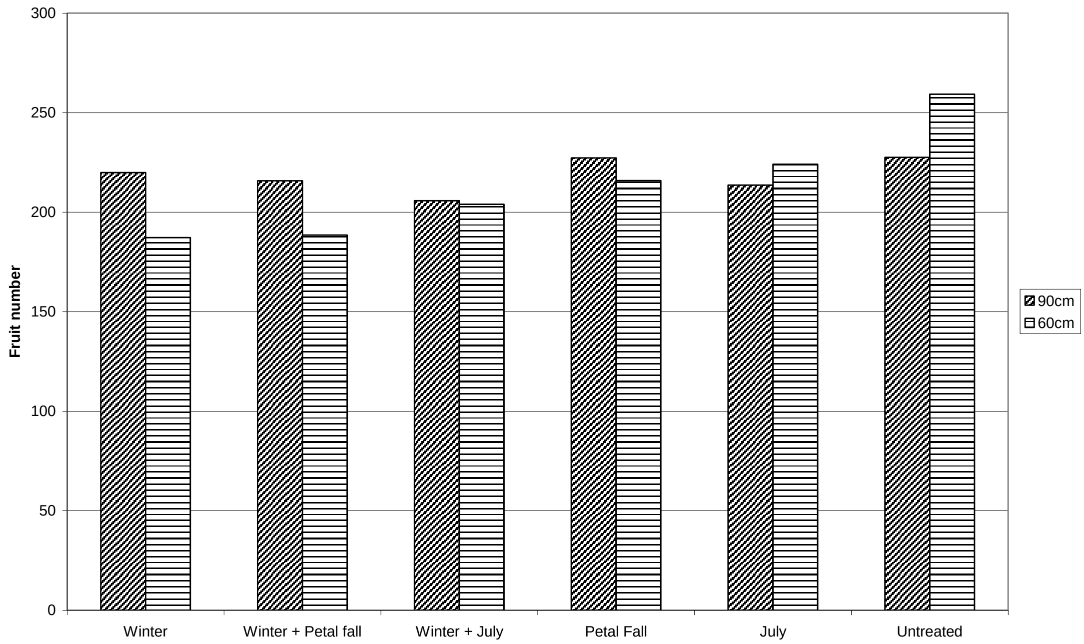


Figure 50. The effect of root pruning on mean fruit number (3 year average) in Cox.

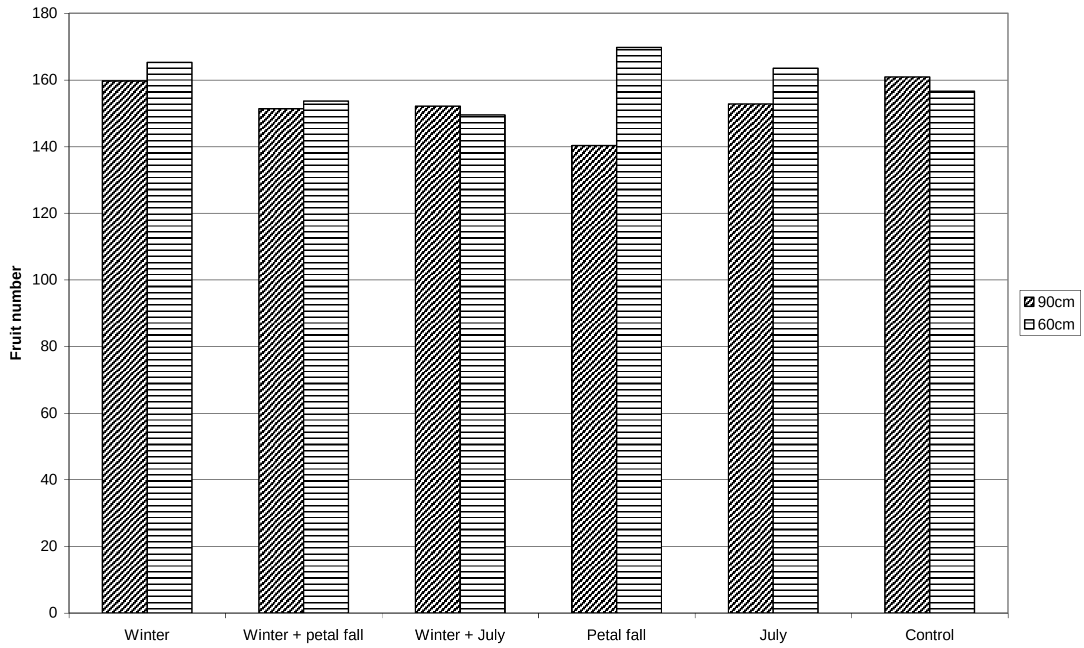


Figure 51. The effect of root pruning on mean fruit number (3 year average) in Conference.

Discussion

The trial has confirmed that root pruning can be employed successfully to reduce vegetative growth in Cox and Conference. The severity of the effect can be adjusted by altering the time of year when the pruning is carried out and/or by changing the distance of the pruning blade from the trunk.

The most sensitive time for root pruning was at petal fall and the least sensitive time was July. Generally the combinations of a winter pruning plus a subsequent cut at petal fall or July gave more growth control than a winter cut on its own or July on its own but less than a single treatment at petal fall.

These findings have shown that growers can choose a series of options best suited for their individual orchards and which are adaptable to growth and cropping patterns developing during the season.

The distance of the pruning from the trunk affected the degree of growth control achieved with the closer distance (ie more root pruned off) giving greater control. This finding again gives growers a degree of flexibility in choosing the distance to suit the amount of growth control required. In order to translate the trial findings to other orchards the report has recorded the approximate percentage of the distance from the trunk to the edge of the canopy that the two (60cm and 90cm) distances relate to.

The effectiveness of the pruning treatments were greater in Conference than in Cox both in terms of overall reduction in growth and also in the numbers of shoots produced. This may be due to a difference in sensitivity to root pruning between Cox and Conference or that the treatments (standardised at 60cm and 90cm from the trunk) resulted in a greater volume of root being severed in the Conference orchard than in the Cox. The results showed an accumulative effect of the treatments in Cox but not in Conference. Again this is a significant finding and growers adopting this technique must be prepared to adjust timings or even leave orchards untreated in some years to prevent trees becoming over controlled.

A reduction in growth as a result of root pruning can lead to improvements in fruit colour but root pruning generally had an adverse affect on fruit size. Differences in crop load made it difficult to determine the precise extent of this effect but generally the closer the pruning distance and the closer the timing to when fruit was on the tree the greater the reduction in fruit size. Clearly this could be an important factor and growers need to be aware that severe root pruning is likely to reduce fruit size.

The trial also investigated the influence that root pruning may have on the uptake of nutrients and water by the tree. Traditional leaf and fruit analysis showed that in Cox compared with controls magnesium and iron levels were generally lower in early season analysis, and magnesium, iron, copper and manganese were generally lower in August. At petal fall in pears nitrogen, phosphorus, magnesium, manganese, copper and zinc levels were generally lower and in August potassium, boron, copper and zinc were generally lower. These differences were normally within 10-15% of the controls.

Sap analysis is a dynamic system of analysing the uptake of nutrients by plants and detects changes in nutrient levels as the tree reacts to changes in soil moisture, growth rates, crop load and weather conditions during different stages of the season. The sap analysis results showed that there were short term reductions of up to 70% in magnesium and potassium levels, which may have contributed to poorer shoot and fruit growth. Restricted water uptake was clearly the major factor.

The trials were carried out on fertile deep brick earth and clay loam soils and growers on less fertile shallower soils may see greater differences. Although the differences in nutrient levels are not the primary cause of the reduced growth and fruit size it would be advisable for growers adopting these techniques to monitor the nutrient status of the trees and to amend their nutrient programmes if necessary.

The soil moisture was monitored by continuous logging at different depths through the soil profile. In the root pruned plots moisture was being extracted at greater depths than in the controls indicating that the trees were having to search deeper because the spread of roots had been restricted by the pruning. As it takes more energy to extract water from deeper in the soil this finding could explain some of the differences, particularly in fruit size, between the treatments. It was noted that in a dry summer (notably 2005) that growth and fruit size were affected more.

Growers adopting this technique, especially in un-irrigated orchards, should be aware of these findings and ideally root prune only in the winter and at the greater distance from the trunk to reduce the adverse affect of moisture stress.

In summary the trial has shown that the technique does work, that it can be adapted to achieve different degrees of growth control and that it can be surmised that some of the adverse effects could be mitigated by supplementary irrigation or soil moisture conservation measures and nutrient applications. These may be more important in pears than in apples.

Conclusions

The trial results have shown that root pruning can reduce growth in both Cox and Conference, giving over 50% reduction in mean extension growth in the most severe treatment. The degree of severity varies according to the time of year and the distance from the trunk that the pruning is carried out.

Mean extension shoot length - Despite some variations between the three years there was generally good consistency of treatment effects throughout the trial, enabling the conclusion to be drawn that the different treatments can be ranked in the following order of degree of growth control as measured by mean extension shoot length.

Least severe	July
↓	Winter
	Winter & July
	Winter & petal fall
Most severe	Petal fall

Average shoot numbers - A similar pattern is shown when the growth control is measured by assessing average numbers of shoots (in some years there were no significant differences between treatments in Cox).

Least severe	July
↓	Winter
	Winter & petal fall
	Winter & July
Most severe	Petal fall

Variety - The root pruning consistently had a greater affect on growth in the Conference plots than in the Cox

Root pruning distance - The 60cm distance from the trunk gave greater growth control than the 90cm distance.

Fruit size - Root pruning can reduce fruit size but as with growth control the degree of this reduction is influenced by both the timing of pruning and the distance from the trunk. Generally pruning at 90cm gave less reduction in fruit size than pruning at 60cm. There was less consistency of treatment effects between the different years, probably due to variability in crop load, but the general pattern was that petal fall treatments gave the greatest reduction in fruit size and winter treatments the least.

Least severe	Winter
↓	July
	Winter & petal fall
	Winter & July
Most severe	Petal fall

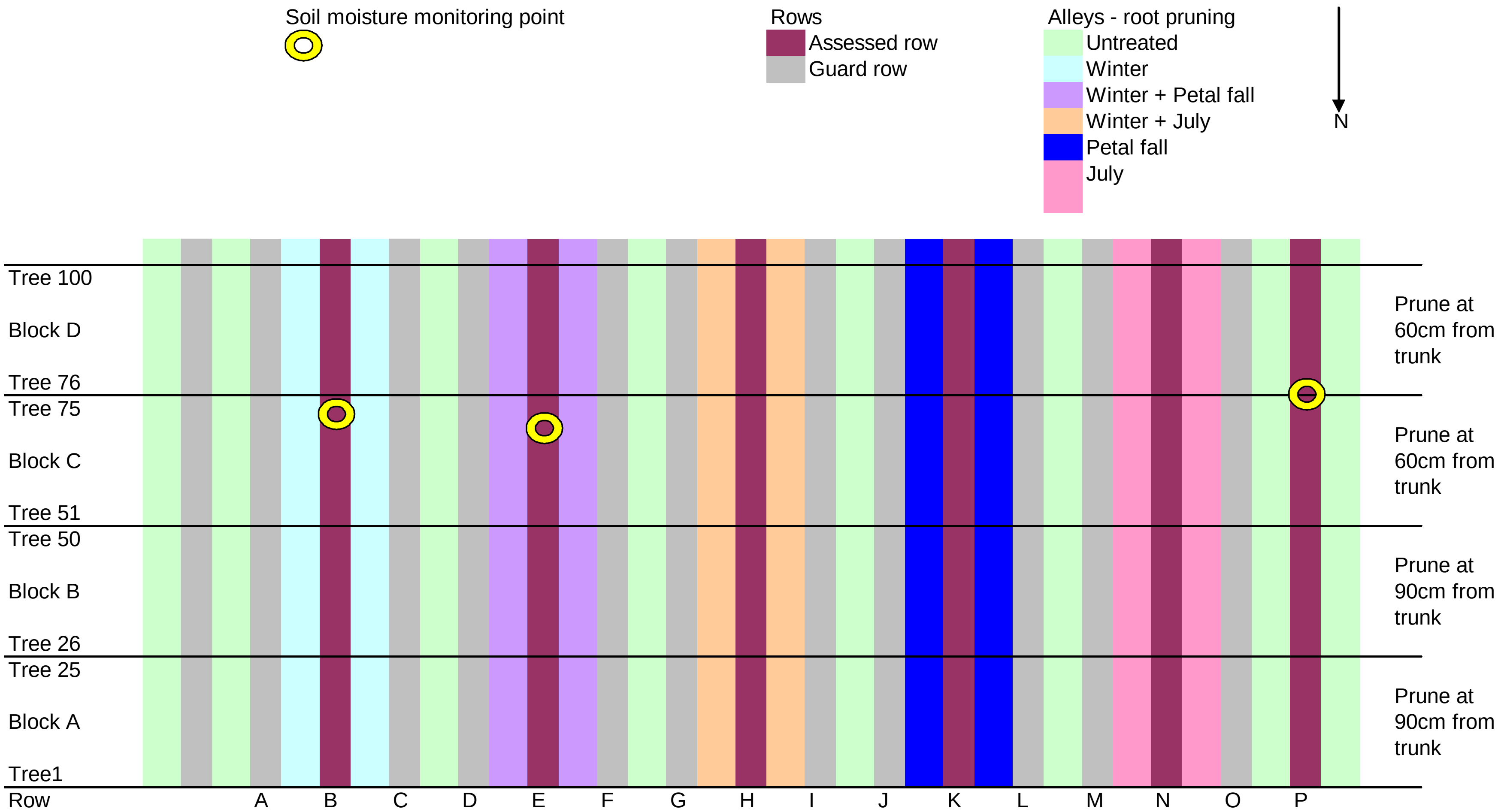
Nutrient uptake - The trial has shown that nutrient uptake can be affected by root pruning treatments. August leaf analysis showed lower levels of phosphorus and potassium, the reduction being worse in Conference and in the first two years of the trial.

Soil moisture - Monitoring showed water being extracted at greater depths in the root pruned plots.

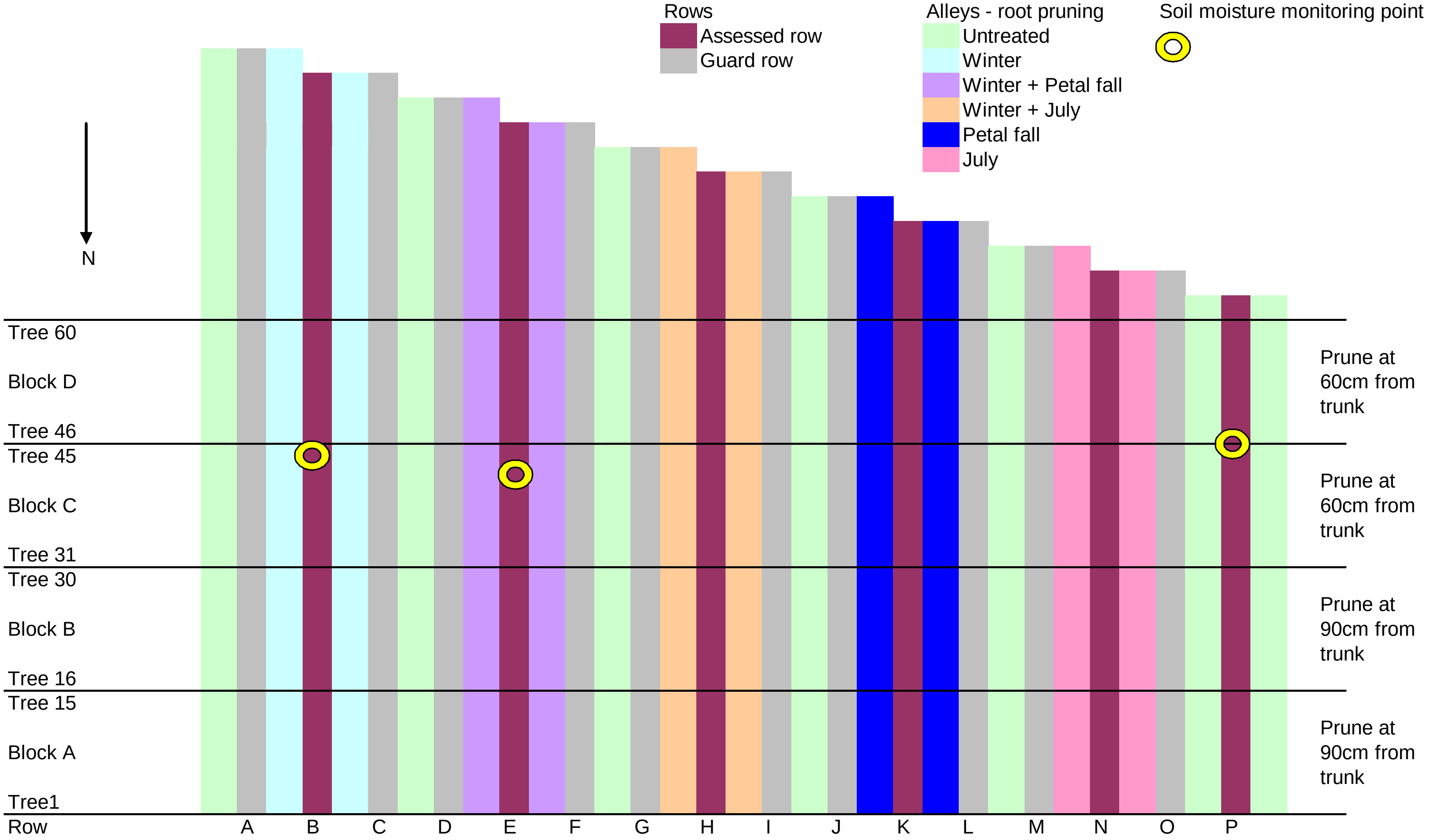
As a result of the trial growers can confidently use root pruning to reduce growth and have information on timing and distance to allow them to reduce the side effects on fruit size. The trial results also indicate that supplementary irrigation and nutrient applications may help alleviate reductions in fruit size.

Appendix I.

Trial layout: Cox



Trial layout: Conference



Appendix II.

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