Project title:	Apples and Pears: Investigation into the effects of root pruning on growth and cropping
Project number:	TF 154
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Previous reports:	None
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Grower co-ordinator:	To be advised
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TF 154

Apples and Pears: Investigation into the effects of Root Pruning on growth and cropping

Grower Summary

Headline

- The first year of the trial has shown that growth control can be achieved by root pruning and that timing of the root pruning has an effect on the amount of growth.
- Fruit size was reduced by root pruning at petal fall but differences in crop load masked the full effect of the pruning treatment.

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 blade on the left hand side of the picture in the guard row.

Background and expected deliverables

Cox, Bramley and to a lesser extent Conference production is 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 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.

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

- 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 Cultar sprays
- Reduce costs (a normal Cultar programme is estimated to be between £145-£345 per hectare per season. 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 organic production

The number of treatment timings and combinations should provide 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

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

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 shown in the soil analysis. Magnesium was reduced in the sap of Cox following the petal fall treatment and calcium and magnesium were reduced in the sap of Conference following petal fall treatment. The soil solution under Conference was shown to contain less calcium. Results from sap analysis show that root pruning has affected nutrient uptake due to the removal of roots where nutrient uptake occurs 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, causes nutrients to be taken up at differing rates.

As root removal reduces potential sites of nutrient uptake, the soil solution from unpruned trees can 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.

From the leaf analysis it can be seen that in Cox and Conference, nitrogen, manganese, copper and zinc are seen to respond positively to the root pruning treatments. These results are in contrast to previous work where root pruning was shown to have no effect on leaf nutrient levels or a reduction in nitrogen level in apple.

The fruit analysis shows a range of trends for mineral content for both Cox and Conference. The fruit analysis for Cox has shown that iron has the greatest response to root pruning treatments. Nitrogen, phosphorous, potassium and magnesium levels were depressed in all treatments and calcium was increased in the winter + July and petal fall treatments. In Conference the levels of nitrogen and iron were depressed in all treatments and the levels of phosphorous were roughly that of the control. Levels of calcium were depressed in the winter + petal fall and petal fall treatments and elevated in the winter and July treatments.

However to interpret the sap, leaf fruit and soil solution results more fully and draw firm conclusions a second seasons data is required.

Between treatments there was no noticeable difference in the pest and disease status for either the Cox or the Conference which supports previous findings.

Root pruning reduced shoot growth with the double treatments having the greatest effect. The single treatments in July had the least effect and appeared to stimulate growth in the Conference and in one of the Cox treatments. In Cox the most severe single treatment was at petal fall reducing growth by 23-26% and in Conference the most severe single treatment was at petal fall reducing growth by 16-18%.

In all cases there was a greater reduction in growth with the closer 60cm treatment than the 90cm treatment, except the July treatment of Conference where there was very slightly more growth from the closer 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.

There was no effect on shoot number in either the Cox or Conference from the root pruning treatments, however an effect may be observed in the second and third years of the trial as this has been the case in some previous research.

Root pruning did however have an effect on fruit size, in Cox the July treatment had the least effect on fruit size and the winter + petal fall treatment had the greatest reduction in fruit size. However for Conference, the winter treatment had a positive effect on fruit size and the petal fall treatment had the greatest reduction in fruit size. It was also shown that the root pruning treatment conducted at 60cm depresses fruit size to a greater extent than the root pruning treatment conducted at 90cm, which is supported by previous research.

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. The trees in this trial had a relatively high fruit number with an average of 207 fruit per tree for Cox and 191 fruit per tree in Conference.
Although fruit size was affected by root pruning treatments the results of fruit number per tree indicated that there was no difference between treatments in this first year for either Cox or Conference.

In summary, the first year of project TF 154 has shown that root pruning can be an effective tool for controlling the shoot growth of Cox and Conference. The distance of treatment application from the trunk and timing of application have been shown to be critical in shoot regeneration but to also have an effect on fruit size. Root pruning has also been shown to have an effect on nutrient uptake and further investigation is required in the second and third years of this project.

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.
- Where a less severe treatment is required, just do the winter cut or just treat one side of the row.
- These are initial recommendations based on one year’s data. Subsequent recommendations will be made after years two and three of the trial.

Science section

Introduction

Cox, Bramley and to a lesser extent Conference production is 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 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.

APRC Contract Report 1271/02/2998 Labour Reduction in apple and pear production (project SP136) refers to UK trials of root pruning, P11 & 14. (Webster unpublished) and FAST Ltd has conducted some very simple observations in several orchards using a subsoiler rather than purpose built machinery. Both 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 may 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 Cultar programme is estimated to be between £145-£345 per hectare per season. The cost of two root pruning operations is estimated to be £120 per hectare giving a net saving of £25-£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. Hallenorff. The Cox (M9) and Conference (QC) orchards are well managed, approximately 7-10 years old and of moderate vigour (i.e. some growth control each year is beneficial) on a clay loam soil type. The Cox orchard has trickle irrigation and facilities to fertigate whereas the Conference orchard does not. 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
(2) 90 cm from the tree trunk

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

(1) Dormant period (16/03/2004)
(2) Petal fall (19/05/2004)
(3) Early July (14/07/2004)
(4) Dormant period and Petal Fall (16/03/2004 and 19/05/2004)
(5) Dormant period and Early July (16/03/2004 and 14/07/2004)
(6) Control, unpruned

Where repeated treatments were applied the root pruning blade was placed in the same place 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 2.

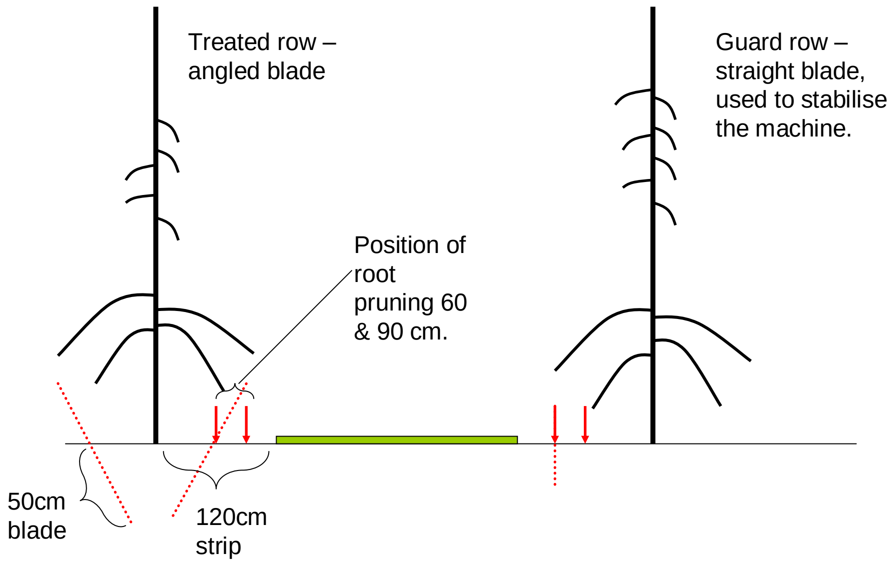


Figure 2. Diagram of treatment application.

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 3. Setting the blade of the root pruner to 90 cm from the tree in Cox.

Figure 4. The root pruning blade prior to insertion into the soil.

Figure 5. Root pruning in 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 is relatively large consisting of between 15 or 25 trees, and the trial is aiming to produce commercial guidelines it was felt that a more complicated and replicated experimental design was unwarranted as this trial will be replicated over time.

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

Within each plot the following were recorded:

- 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)
- 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 analyses per plot (1 fruit from each tree in the plot)
- Pest and disease status (a visual assessment of each plot at monthly intervals)
- Extension growth (all the shoots on 3 trees per plot)
- Shoot number (3 trees per plot)
- Yield (fruit numbers on 5 trees per plot)
- Fruit size (measure 200 fruits per plot)

Results

Effects of root pruning on flower number

The Cox flower buds were visually assessed at full bloom on the 29th April 2004 with 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 1.

Table 1. Cox flower bud score.

Root pruning timing	Distance	Flower bud score
Dormant period	90 cm	8
Dormant period	60 cm	6
Petal fall	90 cm	8
Petal fall	60 cm	8
Early July	90 cm	9
Early July	60 cm	8.5
Dormant period and Petal Fall	90 cm	8.5
Dormant period and Petal Fall	60 cm	8.5
Dormant period and Early July	90 cm	9
Dormant period and Early July	60 cm	8.5
Control, unpruned	(equivalent to 90 cm)	9
Control, unpruned	(equivalent to 60 cm)	8

The Conference flower buds were visually assessed at full bloom on the 19th April 2004 with 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.

Root pruning timing	Distance	Flower bud score
Dormant period	90 cm	8
Dormant period	60 cm	8
Petal fall	90 cm	8
Petal fall	60 cm	8
Early July	90 cm	8
Early July	60 cm	8
Dormant period and Petal Fall	90 cm	8
Dormant period and Petal Fall	60 cm	8
Dormant period and Early July	90 cm	8
Dormant period and Early July	60 cm	8
Control, unpruned	(equivalent to 90 cm)	8
Control, unpruned	(equivalent to 60 cm)	8

It can be seen that in the case of Cox that all trees have a reasonable number of flower buds although there is some variability between treatments, both timing of application of root pruning and distance of root pruning application. However it was also observed that there was a difference in flower number between different ends of the control row, indicating differences due to environmental conditions, hence the observed differences between treatments may not be due to treatments but other factors influenced by the soil, such as nutrition of water availability.

In the case of Conference no differences were observed in flower number between any of the treatments.

As this trial is replicated over time and as there may be a compounding effect of treatment applications, differences between treatments may become apparent in subsequent years.

Effects of root pruning on fruit set

The Cox fruit set was visually assessed at the 15mm fruit stage with 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.

Root pruning timing	Distance	Fruit set score
Dormant period	90 cm	8
Dormant period	60 cm	7
Petal fall	90 cm	8
Petal fall	60 cm	8
Early July	90 cm	8
Early July	60 cm	8
Dormant period and Petal Fall	90 cm	8
Dormant period and Petal Fall	60 cm	8
Dormant period and Early July	90 cm	9
Dormant period and Early July	60 cm	8
Control, unpruned	(equivalent to 90 cm)	8
Control, unpruned	(equivalent to 60 cm)	8

The Conference fruit set was visually assessed at the 15mm fruit stage with 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.

Root pruning timing	Distance	Fruit set score
Dormant period	90 cm	8
Dormant period	60 cm	8
Petal fall	90 cm	8
Petal fall	60 cm	8
Early July	90 cm	8
Early July	60 cm	8
Dormant period and Petal Fall	90 cm	8
Dormant period and Petal Fall	60 cm	8
Dormant period and Early July	90 cm	8
Dormant period and Early July	60 cm	8
Control, unpruned	(equivalent to 90 cm)	8
Control, unpruned	(equivalent to 60 cm)	8

Both the Cox and the Conference show good fruit set in all treatments.

Effects of root pruning on sap analysis

The following graphs express 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 effects of root pruning distance from the tree will be examined closely in years 2 and 3 of the trial. The graphs also show a line indicating optimum level based on historical data for the crop, relative to the control treatment.

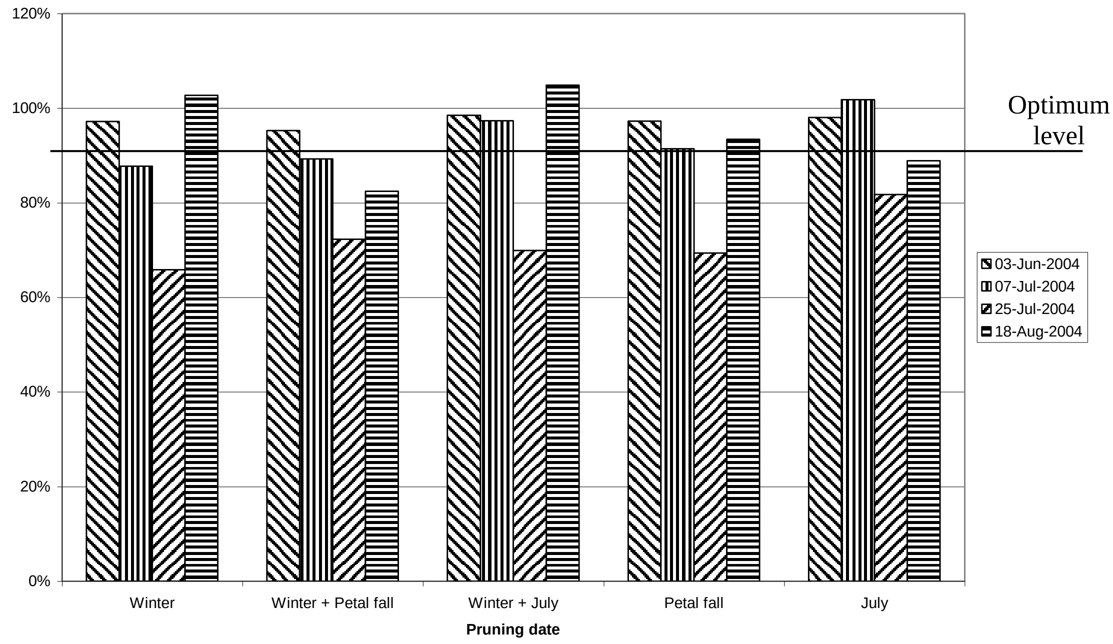


Figure 5. Potassium levels in the sap of Cox leaves expressed as a percentage of the control treatment.

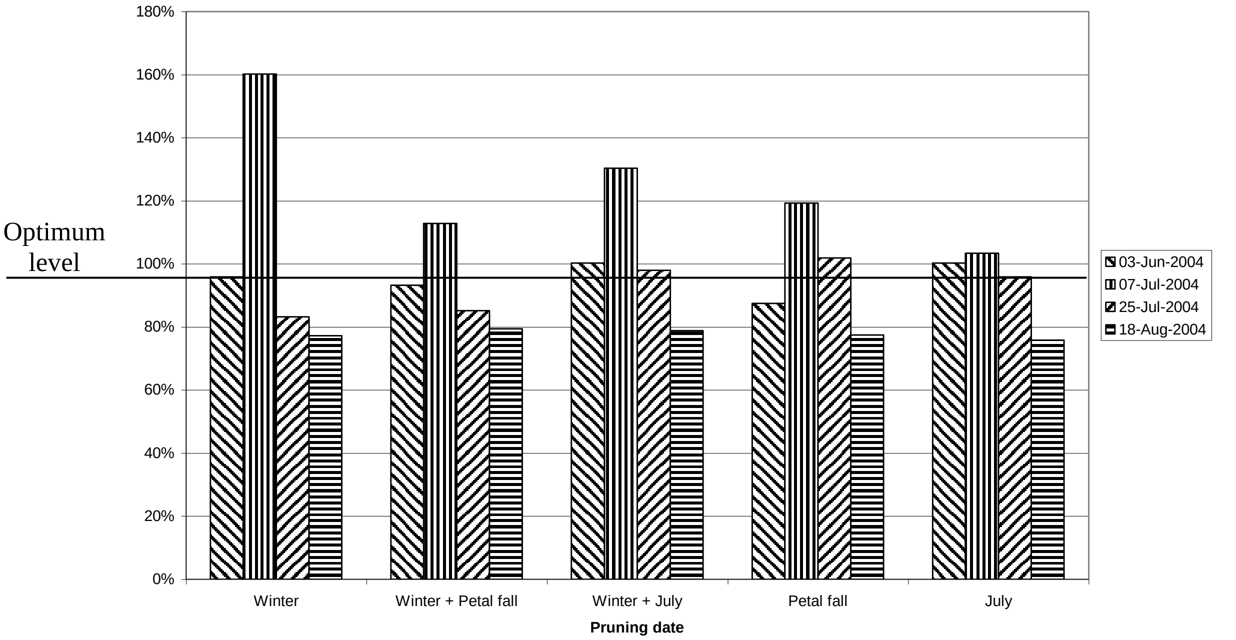


Figure 6. Calcium levels in the sap of Cox leaves expressed as a percentage of the control treatment.

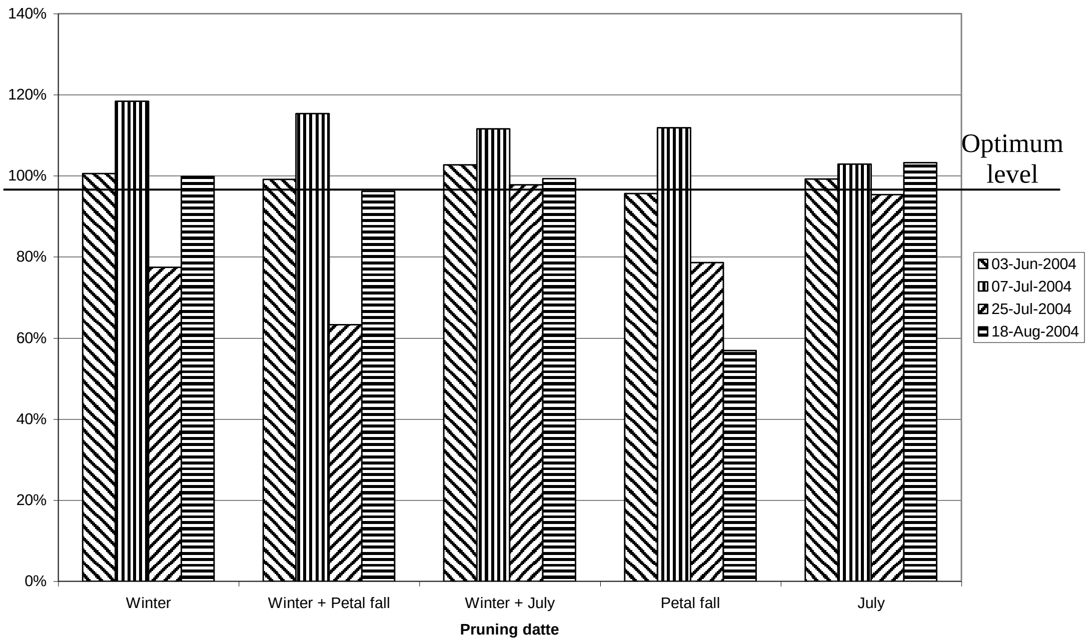


Figure 7. Magnesium levels in the sap of Cox leaves expressed as a percentage of the control treatment.

It can be seen from Figures 5-7 that root pruning has affected nutrient uptake in Cox. In Figure 5 it can be seen that potassium levels fall on the 25th July sampling but increase by the 18th August. However only in the winter and winter + July treatments do levels return to that of the control. Figure 6 shows that root pruning prior to 7th July stimulates calcium uptake levels at this time, however by the 18th August the levels have fallen to less than 80% of the control treatment. Figure 7 shows that July root pruning has little effect on magnesium uptake on the 18th August. However winter, winter + petal fall and petal fall have markedly reduced levels of magnesium on the 25th July. However all magnesium levels rise to normal levels on the 18th August apart for the petal fall root pruning.

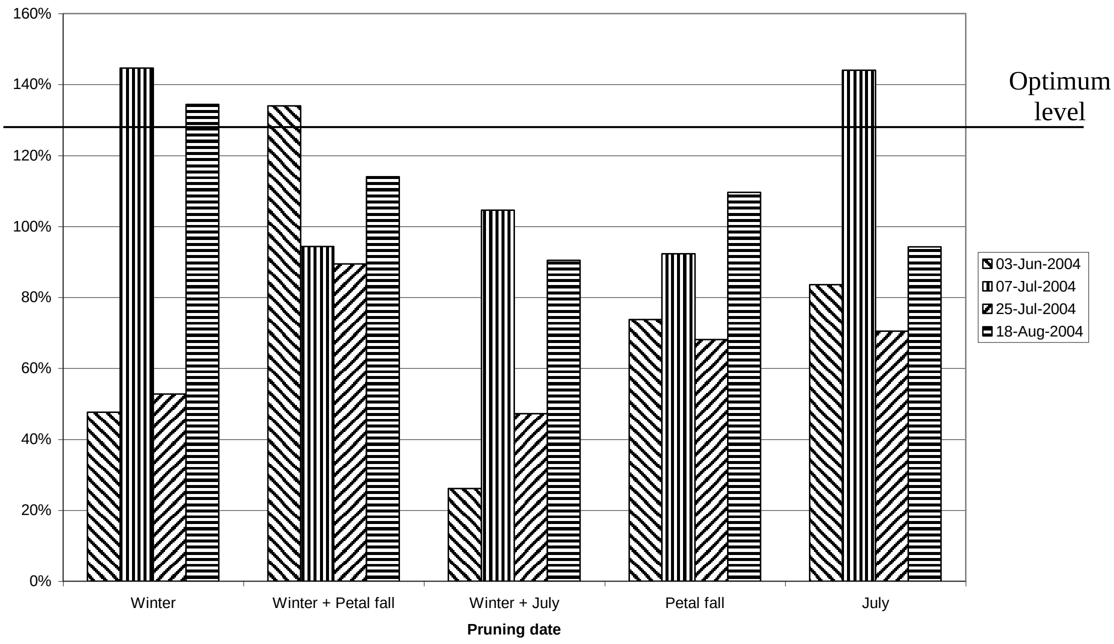


Figure 8. Potassium levels in the sap of Conference leaves expressed as a percentage of the control treatment.

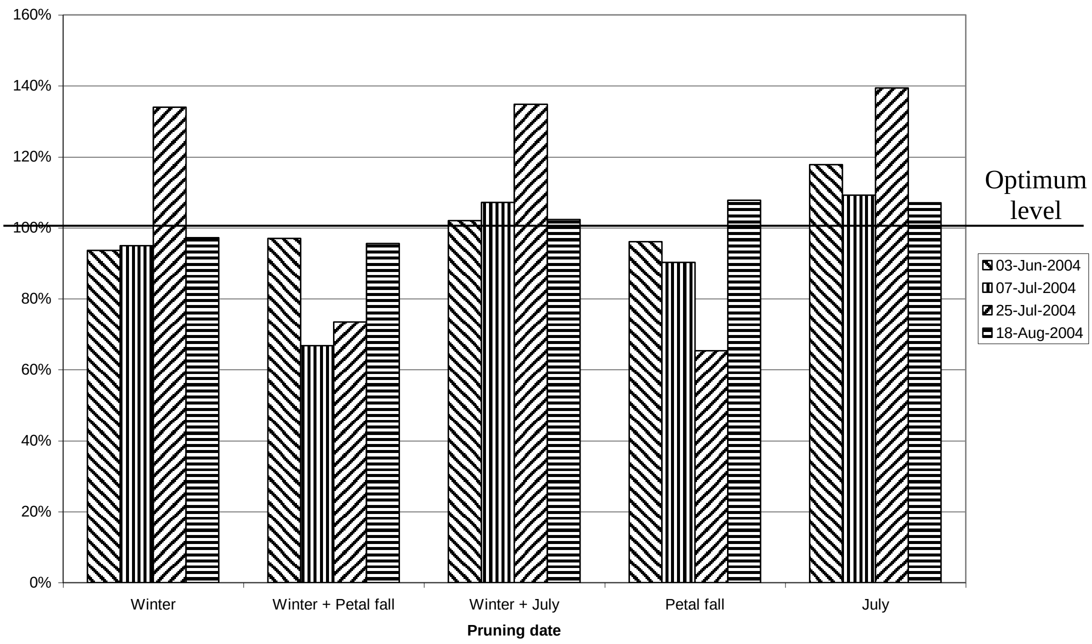


Figure 9. Calcium levels in the sap of Conference leaves expressed as a percentage of the control treatment.

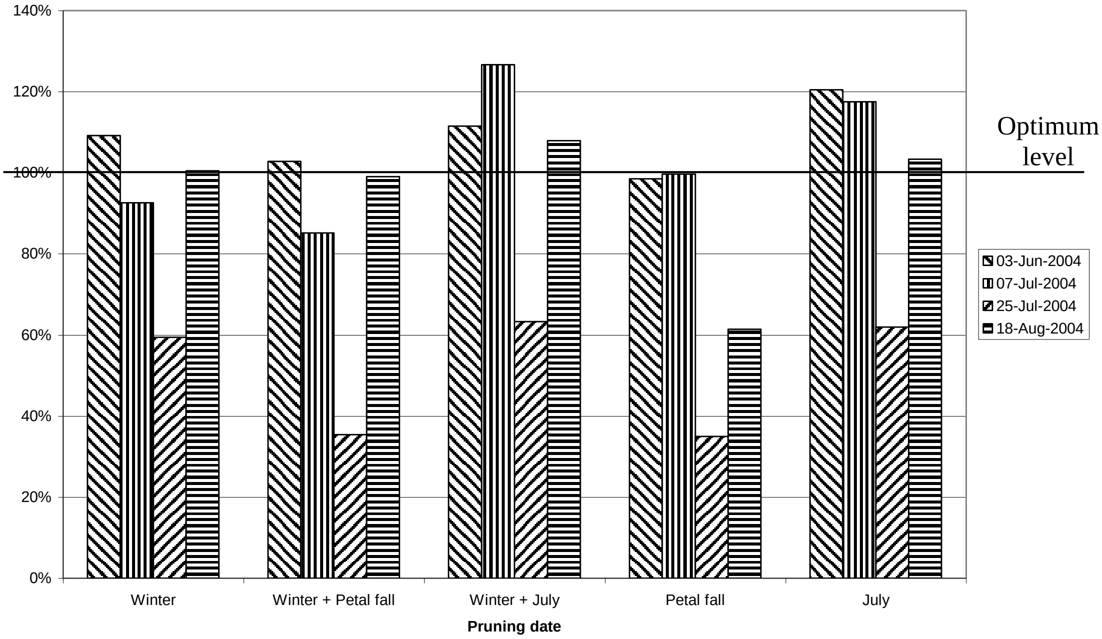


Figure 10. Magnesium levels in the sap of Conference leaves expressed as a percentage of the control treatment.

Figures 8-10 also show root pruning to have an effect of nutrient uptake. Figure 8 shows a drop in the potassium levels of the sap in late July in all treatments when compared with the control, but these levels recover to that of around the control by mid-August. This may indicate that due to the root pruning reducing the volume of roots, potassium uptake becomes limiting during periods of high demand within the plant. Figure 9 shows reduced calcium uptake in any treatments associated with petal fall. Figure 10 shows a depression in all treatments compared to the control for magnesium levels in late July, however they recover by mid August in all cases except for the petal fall treatment.

Effects of root pruning on soil analysis

The following graphs express nutrient levels in the soil 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 effects of root pruning distance from the tree will be examined closely in years 2 and 3 of the trial. The graphs also show a line indicating optimum level based on historical data for the crop, relative to the control treatment.

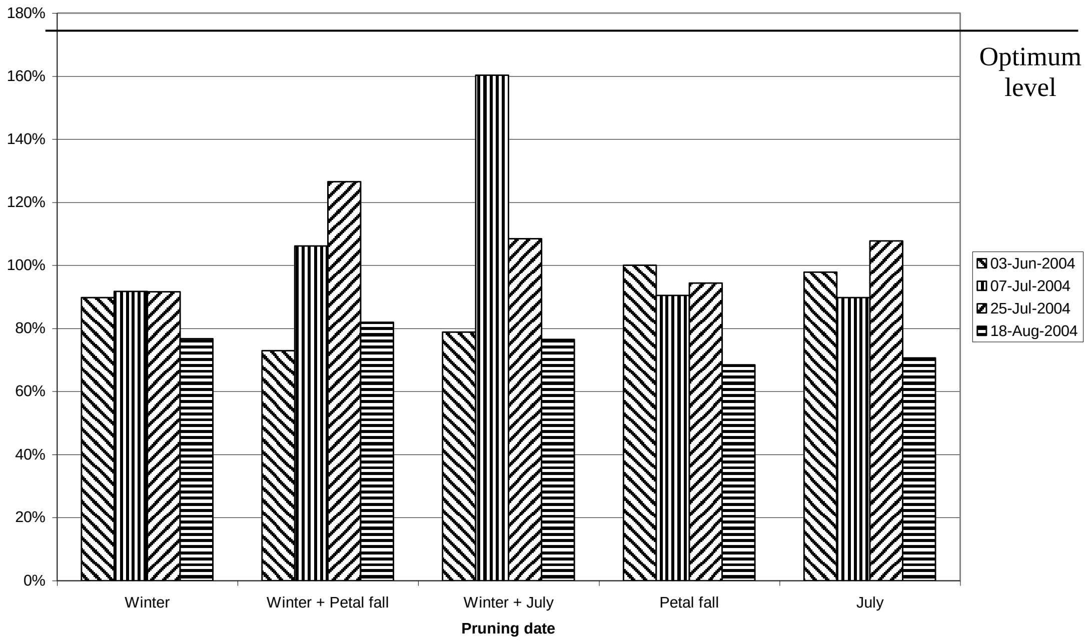


Figure 11. Potassium levels in the soil solution under Cox expressed as a percentage of the control treatment.

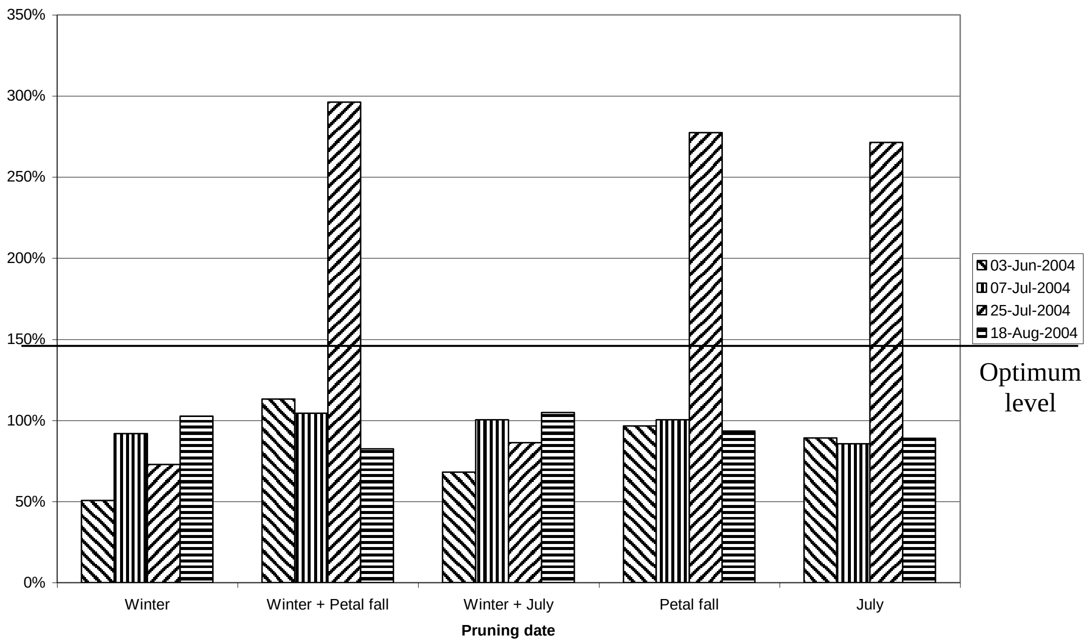


Figure 12. Calcium levels in the soil solution under Cox expressed as a percentage of the control treatment.

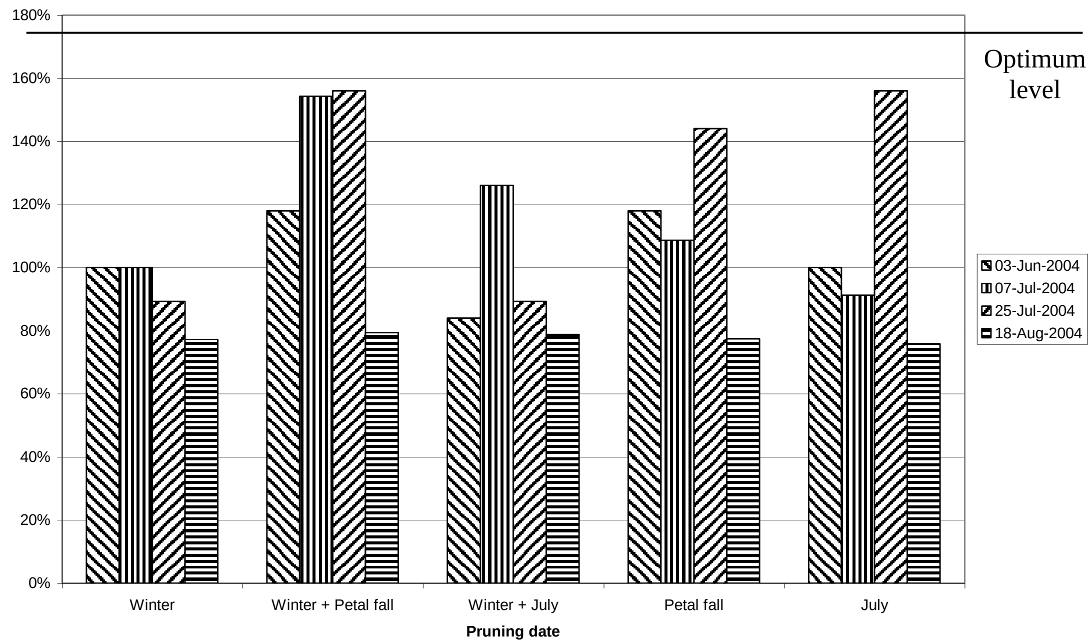


Figure 13. Magnesium levels in the soil solution under Cox expressed as a percentage of the control treatment.

It can be seen in Figure 11 that the winter and petal fall root pruning treatments have lower quantities of potassium in the soil solution than the control. Winter + petal fall and winter + July pruning treatments have greater quantities of potassium in the soil solution than the control for the 7th and 25th July sampling dates. This suggests that uptake has been reduced; however this assumption is not confirmed by the sap analysis. Figure 12 shows that for the Winter + petal fall, petal fall and July root pruning treatments calcium is present in far greater quantities than in the control for the 25th July, however this again does not correlate with sap analysis. As the results of the sap analysis indicate near normal levels in the plant, it is possible that more calcium has become available in the soil solution under these treatments. Figure 13 shows that root pruning interacts with magnesium levels in the soil and that winter pruning alone has the least effect compared to the control. The results show that magnesium levels in the soil rise after the occurrence of the root pruning treatments; this may indicate that the root pruning treatment can interfere with magnesium uptake.

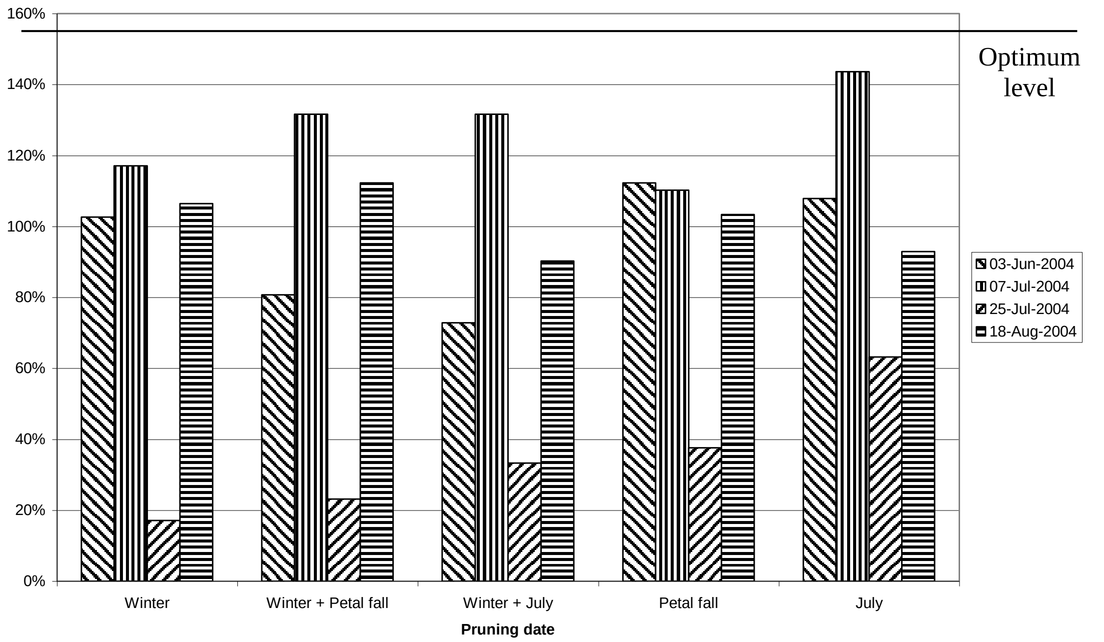


Figure 14. Potassium levels in the soil solution under Conference expressed as a percentage of the control treatment.

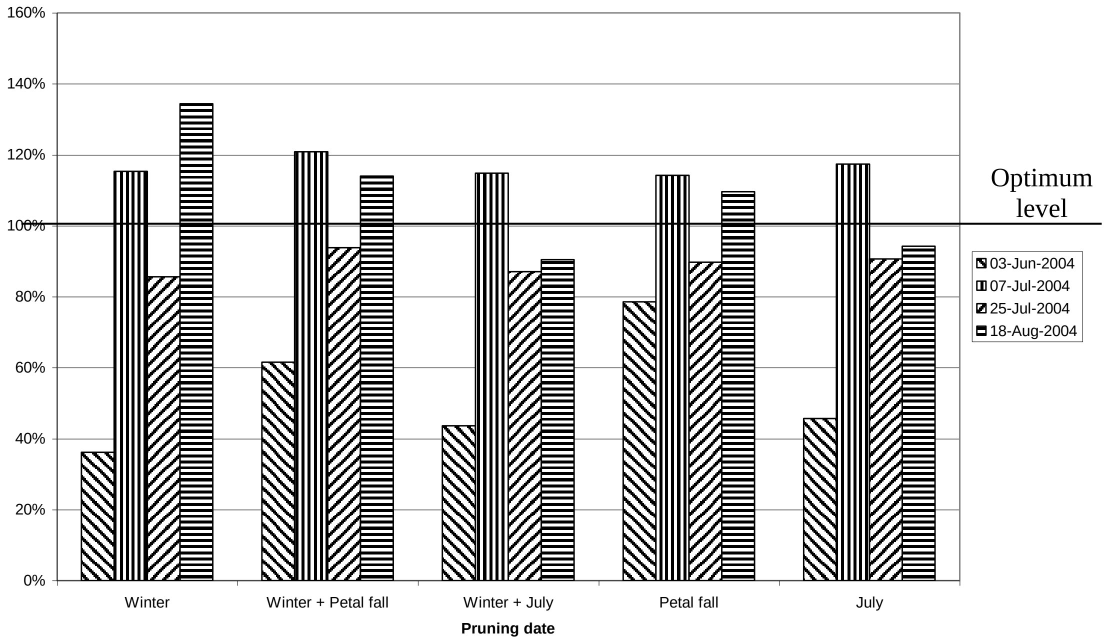


Figure 15. Calcium levels in the soil solution under Conference expressed as a percentage of the control treatment.

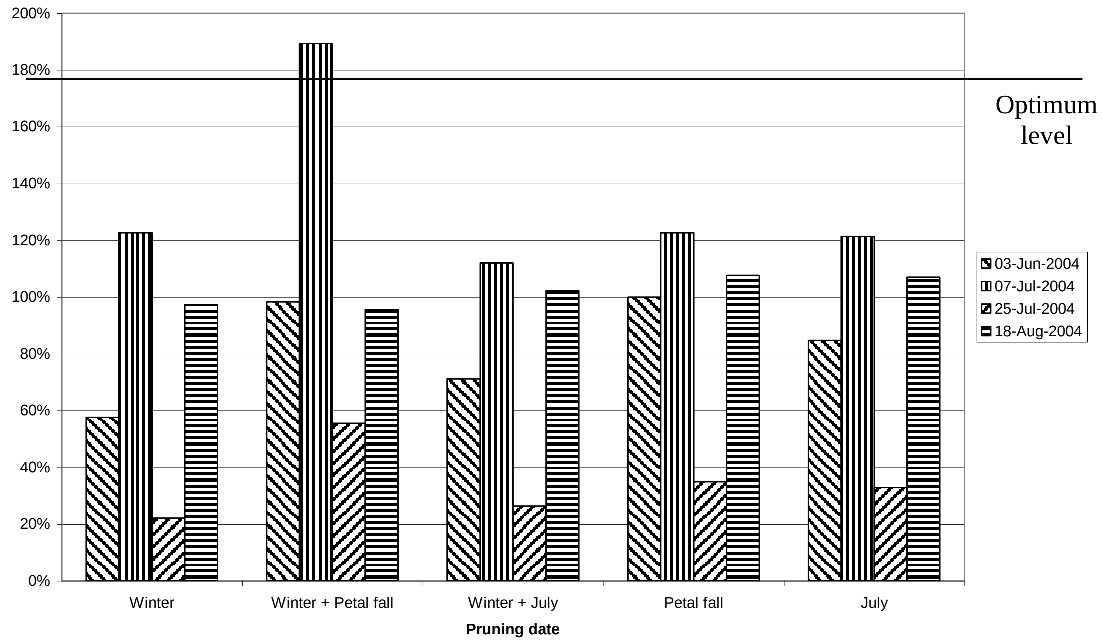


Figure 16. Magnesium levels in the soil solution under Conference expressed as a percentage of the control treatment

Figures 14-16 show differences in potassium, calcium and magnesium in the soil under Conference. Figure 14 and 16 show a fluctuation in the levels of potassium and magnesium but the drop on the 25th July in both cases is unexplained. Figure 15 shows that in all cases the level of calcium is less than the control but again this is unexplained.

Effects of root pruning on leaf analysis

The following graphs express 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 effects of root pruning distance from the tree will be examined closely in years 2 and 3 of the trial. The graphs also show a line indicating optimum level based on historical data for the crop, relative to the control treatment.

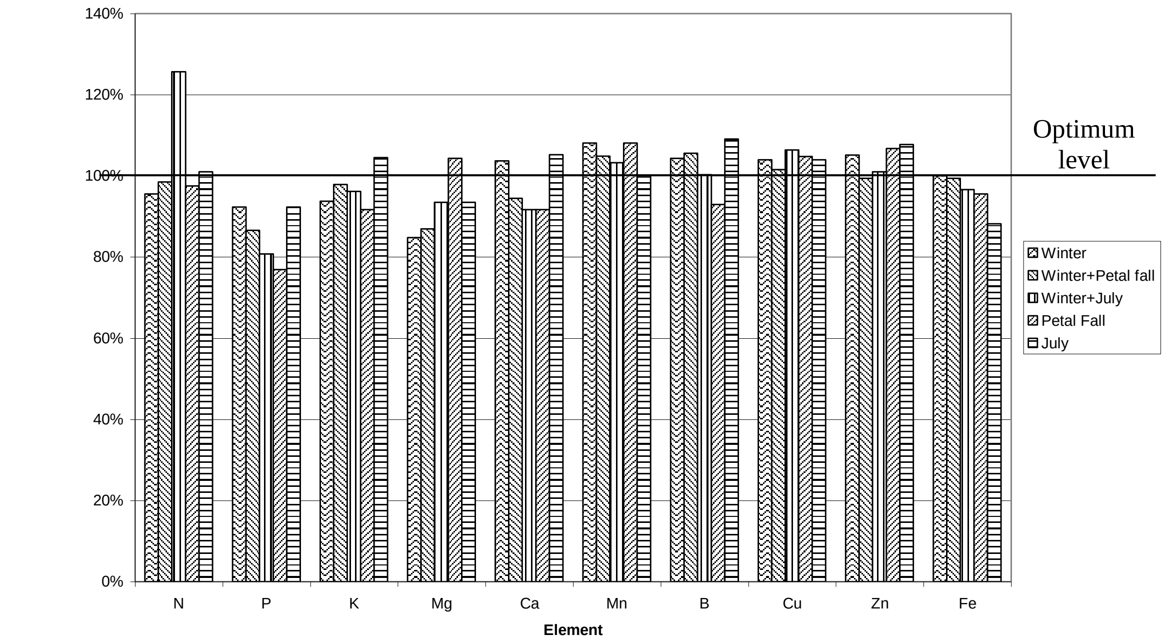


Figure 17. Nutrient levels in the leaves of Cox on 31st August expressed as a percentage of the control treatment.

It can be seen in Figure 17 that more nitrogen has accumulated in the Cox leaves for the winter + July treatment. Manganese, copper and zinc are seen to respond positively to each of the treatments.

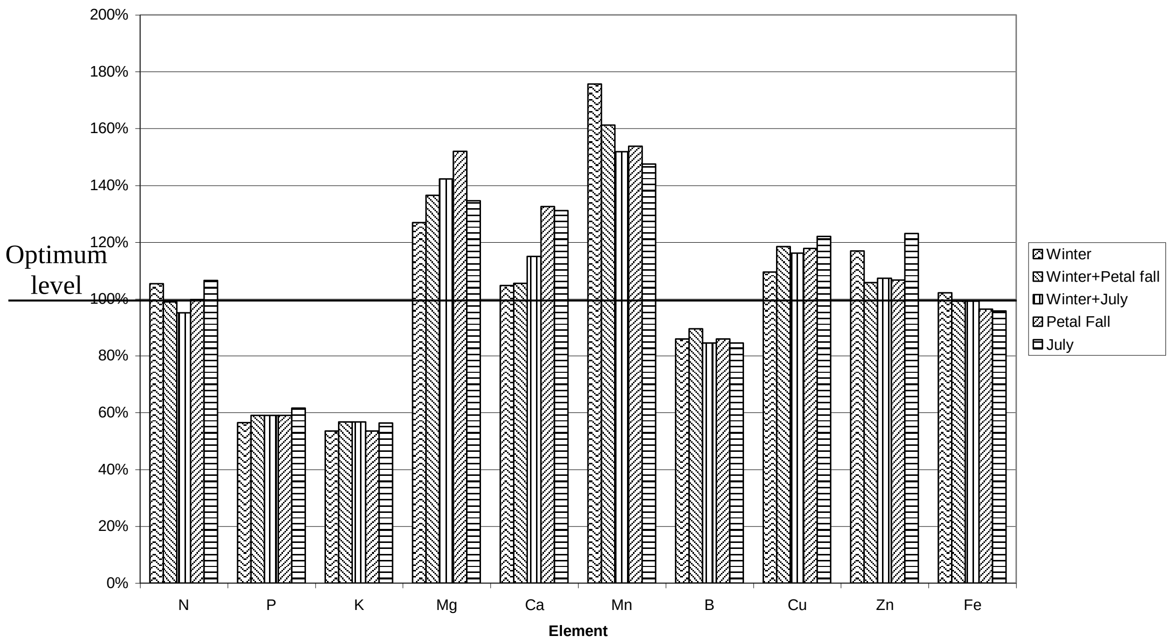


Figure 18. Nutrient levels in the leaves of Conference on 25th August expressed as a percentage of the control treatment.

It can be seen in Figure 18 that phosphorous, potassium and boron are reduced in the leaves of Conference for all root pruning treatments. Conversely magnesium, calcium, manganese, copper and zinc are all elevated in the leaves of Conference for all root pruning treatments.

Effects of root pruning on fruit analysis

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 effects of root pruning distance from the tree will be examined closely in years 2 and 3 of the trial. The graphs also show a line indicating optimum level based on historical data for the crop, relative to the control treatment.

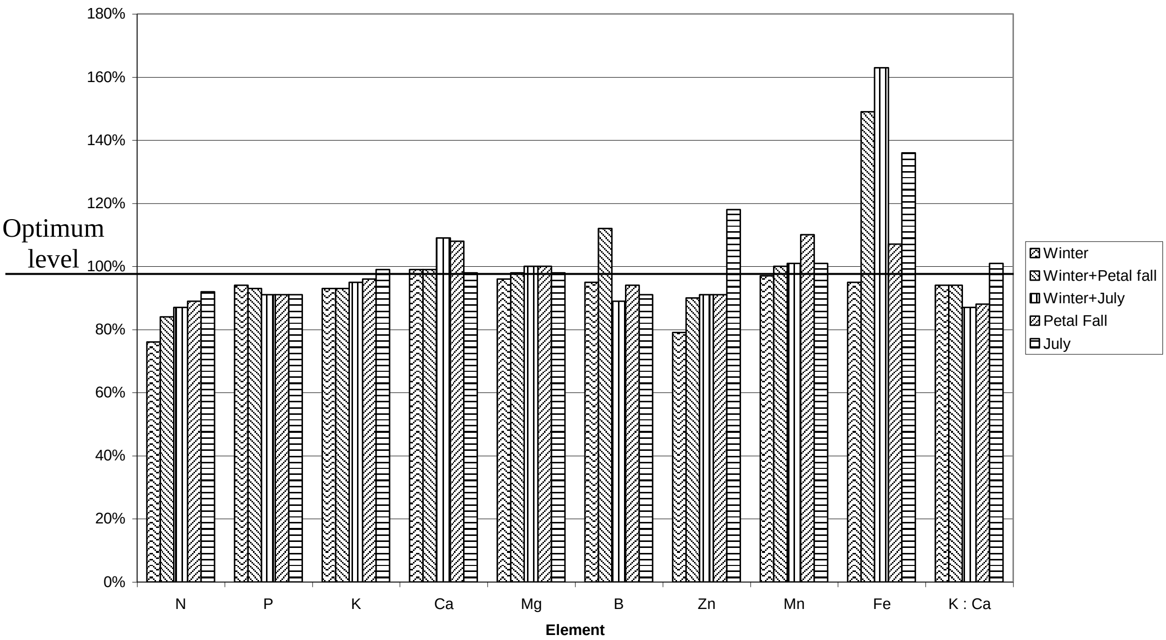


Figure 19. Nutrient levels in the fruit of Cox 31st August expressed as a percentage of the control treatment.

It can be seen from Figure 19 that iron shows the greatest response to root pruning treatments. Nitrogen, phosphorous, potassium and magnesium levels are depressed in all treatments and calcium is increased in the winter + July and petal fall treatments.

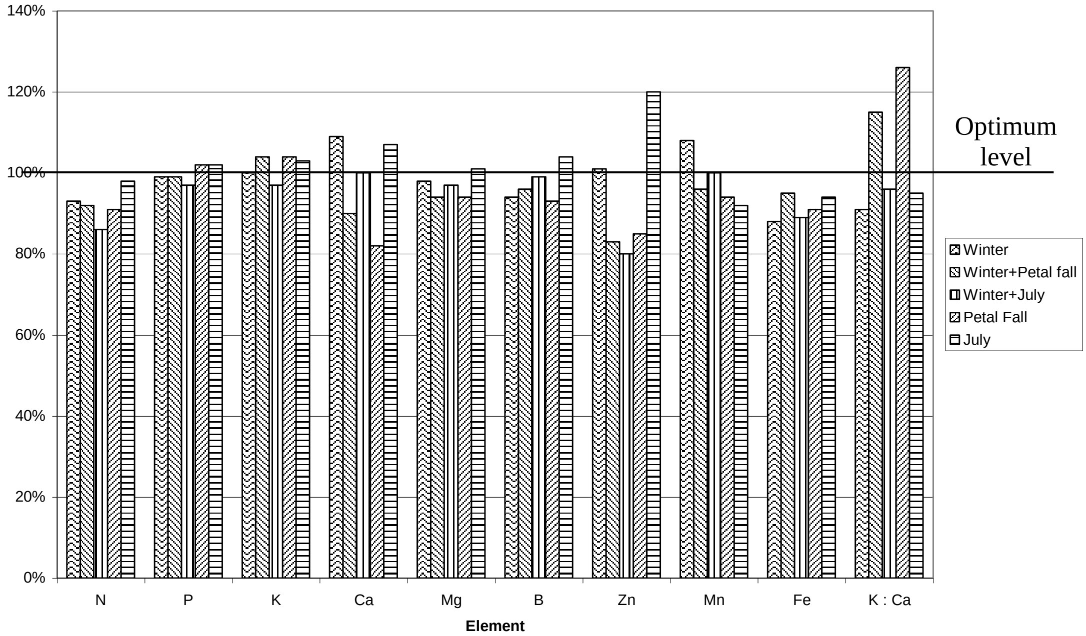


Figure 20. Nutrient levels in the fruit of Conference on 25th August expressed as a percentage of the control treatment.

It can be seen from Figure 20 that the levels of nitrogen and iron are depressed in all treatments. Levels of phosphorous are roughly that of the control and levels of calcium are depressed in the winter + petal fall and petal fall treatments and elevated in the winter and July 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.

Effects of root pruning on extension growth

The extension growth of one season was recorded and is presented below:

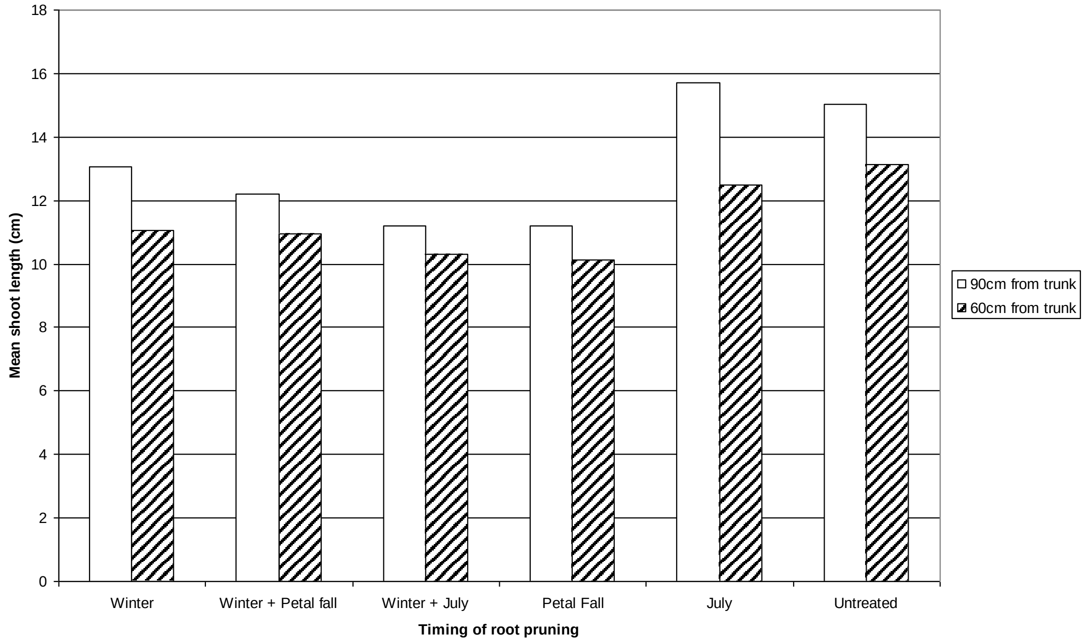


Figure 21. The effect of root pruning on mean extension growth in Cox (for the Untreated columns, 90cm corresponds to blocks A & B and 60cm corresponds to blocks C & D).

Results were similar for both Cox and Conference. The single treatments in July had the least effect on shoot elongation and appeared to stimulate growth in the pears and one of the apple treatments. Figure 21 shows that the most severe single treatment on Cox was at petal fall reducing growth by 23-26%. Winter + July gave a similar growth reduction and winter treatment alone controlled growth by 14-16%.

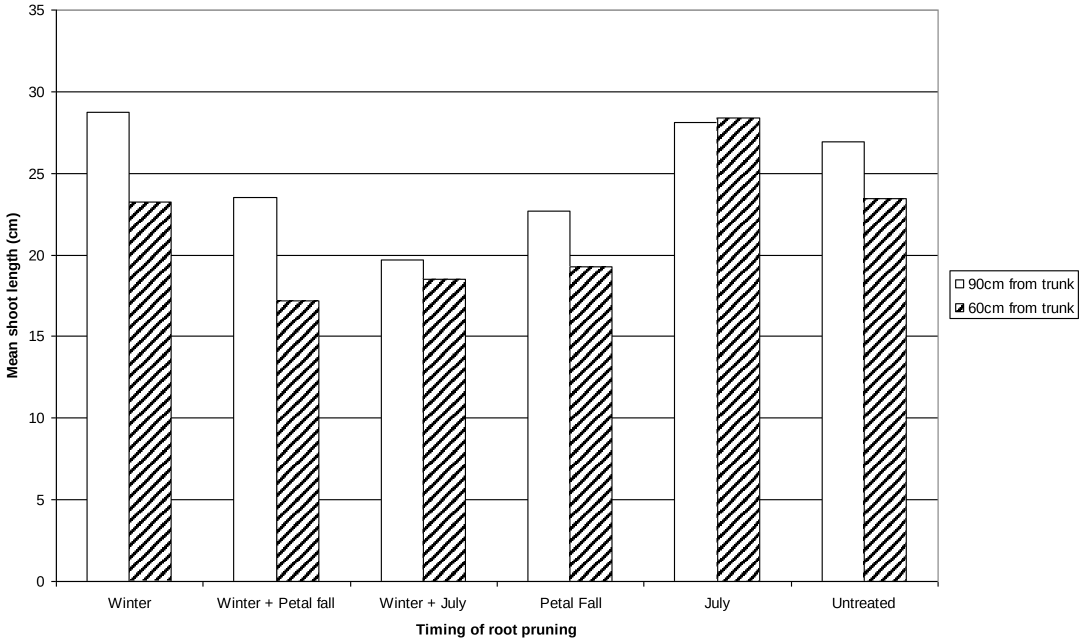


Figure 22. The effect of root pruning on mean extension growth in Conference (for the Untreated columns, 90cm corresponds to blocks A & B and 60cm corresponds to blocks C & D).

Figure 22 shows that the most severe single treatment was at petal fall reducing growth by 16-18%. The combined winter + petal fall or July increased the growth control by a further 6-10%. Root pruning reduced shoot growth with the double treatments having the greatest effect.

Effects of root pruning on shoot number

It can be seen in Figures 23 and 24 that there was a greater effect of position of the tree in the row than from the treatments applied which can be seen in the large variation between the two ends, A+B and C+D, of the untreated row.

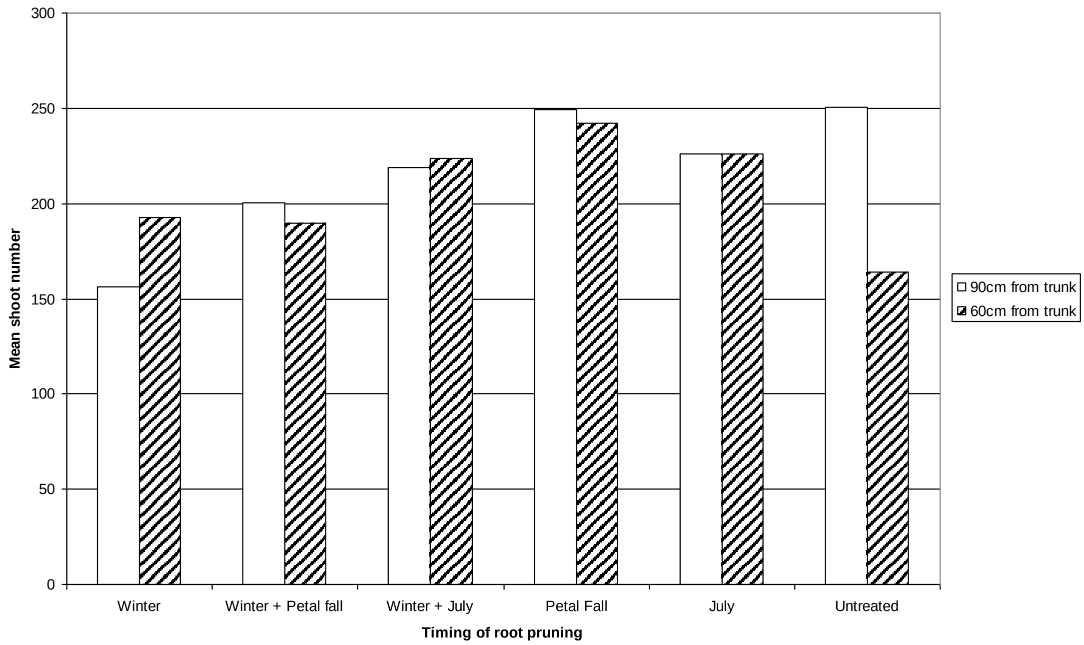


Figure 23. The effect of root pruning on shoot number in Cox (for the Untreated columns, 90cm corresponds to blocks A & B and 60cm corresponds to blocks C & D).

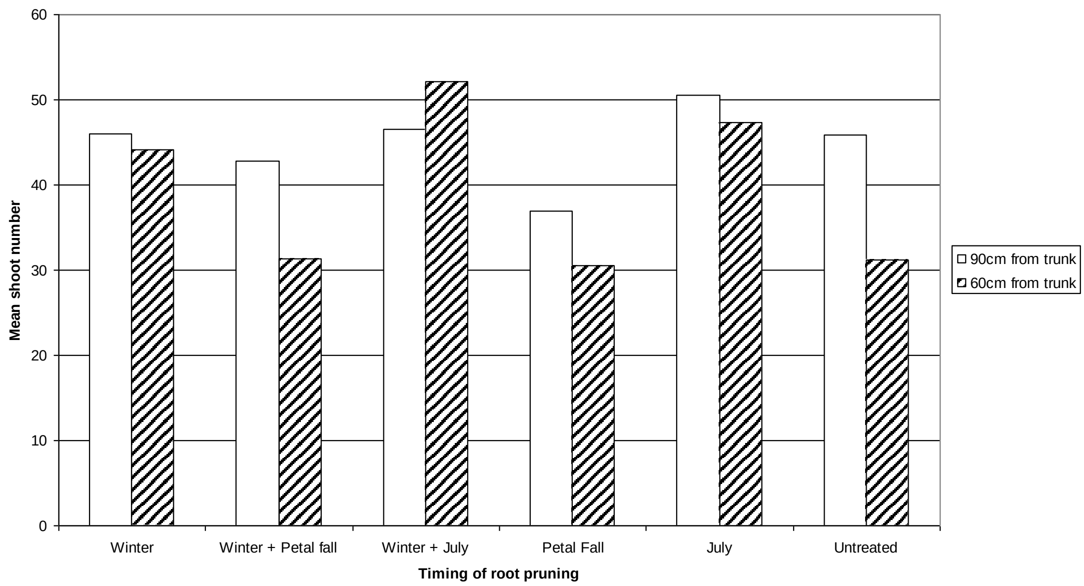


Figure 24. The effect of root pruning on shoot number in Conference (for the Untreated columns, 90cm corresponds to blocks A & B and 60cm corresponds to blocks C & D).

Effects of root pruning on fruit size

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

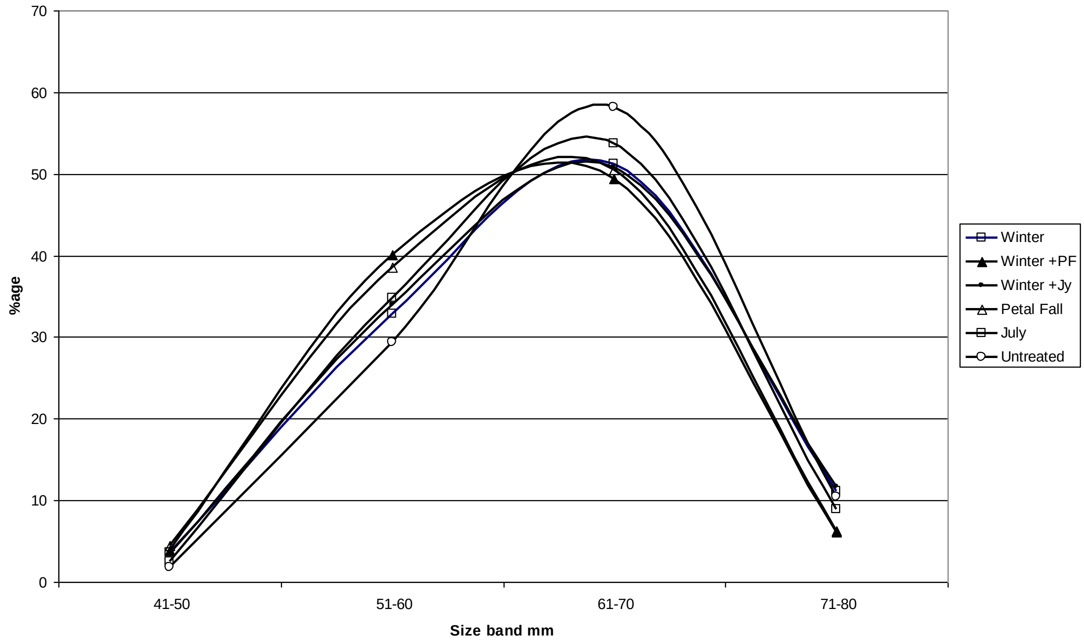


Figure 25. The effect of root pruning treatment on fruit size distribution in Cox.

It can be seen from Figure 25 that all treatments resulted in a slight decrease in fruit size i.e. the curves moved to the left of the control curve. Of these treatments, the July treatment results in the least reduction in fruit size and the winter + petal fall treatment shows the greatest reduction in fruit size.

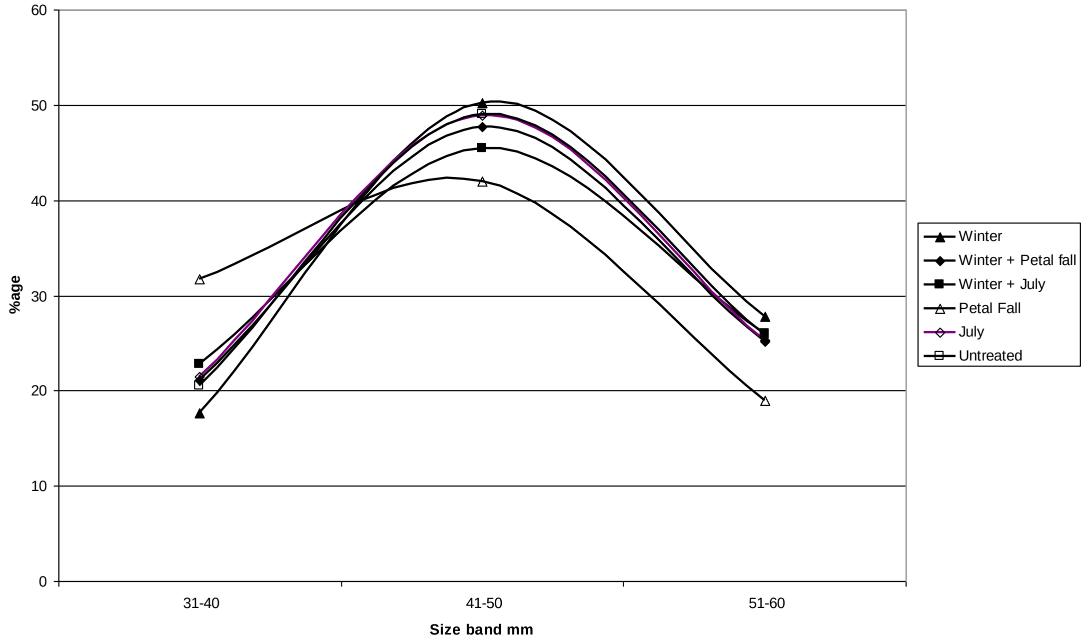


Figure 26. The effect of root pruning treatment on fruit size distribution in Conference.

It can be seen from Figure 26 that the winter treatment has positive effect on fruit size and the petal fall treatment has the greatest reduction in fruit size.

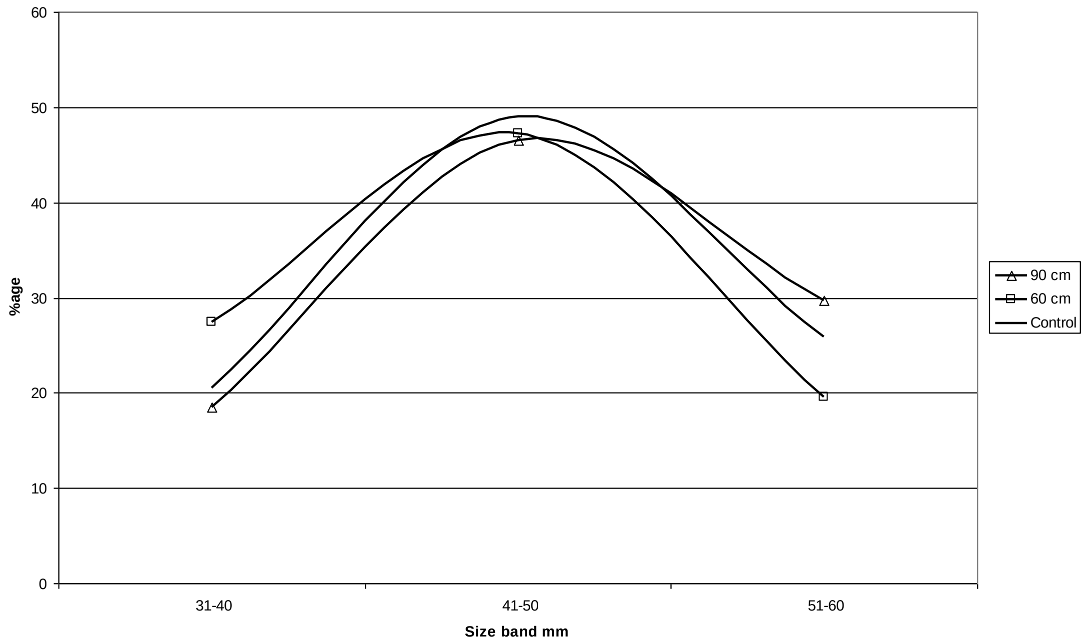


Figure 27. The effect of root pruning distance on fruit size distribution in Conference.

It can be seen from Figure 27 that the root pruning treatment conducted at 60cm results in an overall depression in fruit size to a greater extent than the root pruning treatment conducted at 90cm. However the 90cm root pruning treatment results in a greater quantity of fruit in the larger size class than the control.

Effects of root pruning on fruit number

The results for fruit number indicated that there was no difference between treatments in either the Cox or the Conference.

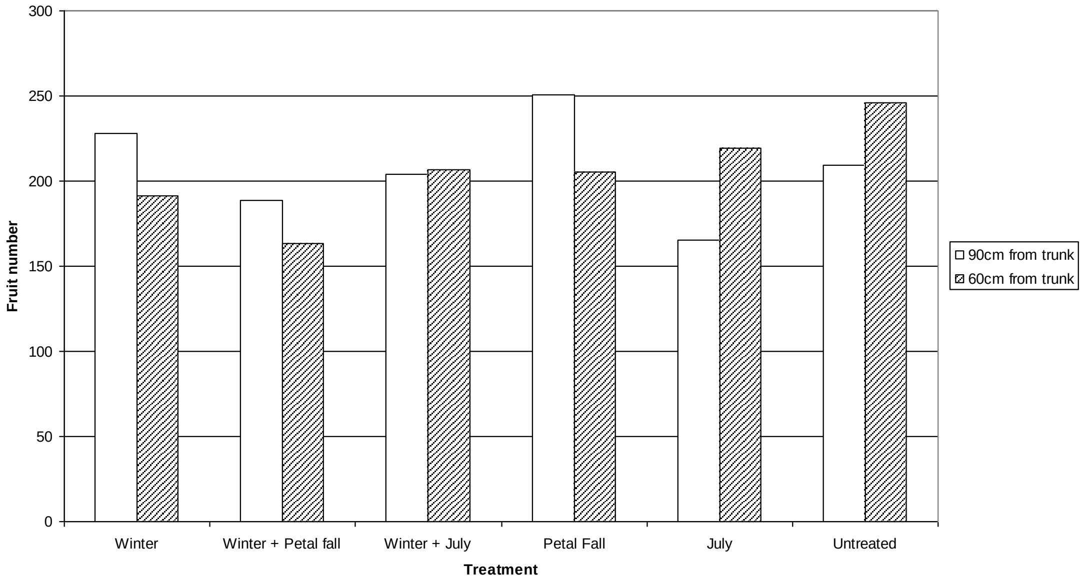


Figure 28. The effect of root pruning treatment on fruit number in Cox (for the Untreated columns, 90cm corresponds to blocks A & B and 60cm corresponds to blocks C & D).

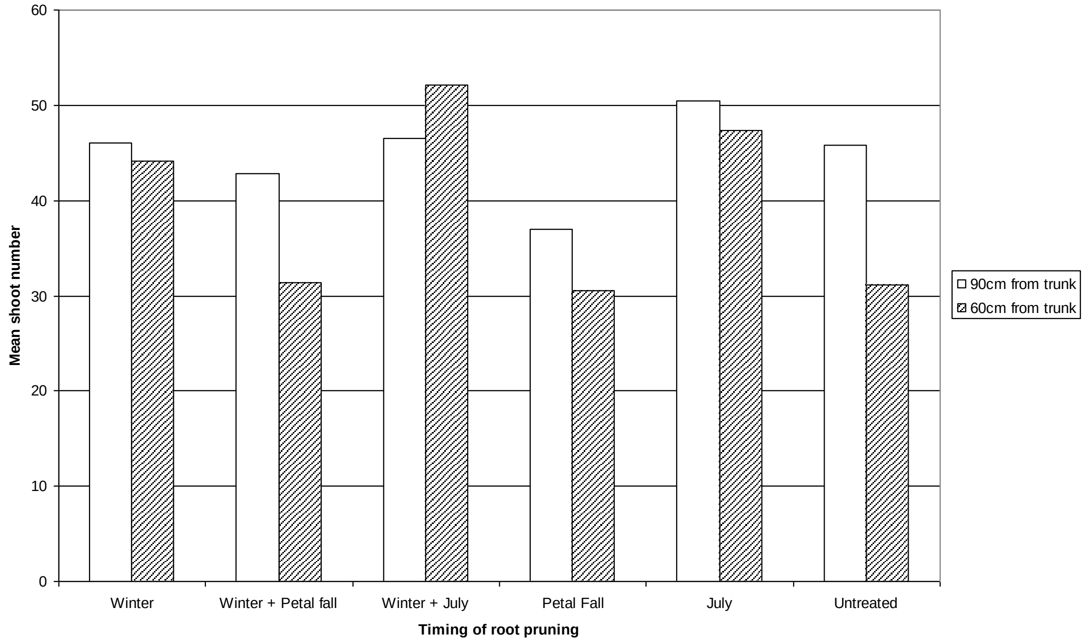


Figure 29. The effect of root pruning treatment on fruit number in Conference (for the Untreated columns, 90cm corresponds to blocks A & B and 60cm corresponds to blocks C & D).

Discussion

There was no effect on flower number or fruit set in either the Cox or the Conference from the initial year of root pruning. Flower number and fruit set may be increased in the second and third years of the trial as other researchers (Webster *et al.*, 2003) have shown that root pruning can increase floral buds and final fruit sets from the second year of root pruning treatments. This could be due to an increase in cytokinin production from increased root regeneration, which may have a positive influence on floral initiation resulting in increased flower numbers.

It can be seen that root pruning has affected nutrient uptake and this can be seen in the sap analysis. In Cox potassium levels fell on the 25th July sampling but increased by the 18th August, however only in the winter and winter + July treatments did levels return to that of the control. Root pruning prior to 7th July stimulated calcium uptake levels at this time, however by the 18th August the levels had fallen to less than 80% of the control treatment. July root pruning had little effect on magnesium uptake on the 18th August; however winter, winter + petal fall and petal fall had markedly reduced levels of magnesium on the 25th July. However all magnesium levels rose to normal levels on the 18th August apart for the petal fall root pruning. Sap analysis for Conference shows reduced calcium uptake in any treatments associated with petal fall. All treatments compared to the control show depressed levels for magnesium on 25th July, however the levels recovered by the 18th August in all cases except for the petal fall treatment.

Root pruning can cause a sudden drastic reduction in the root volume of a tree followed by varying degrees of root regeneration. The effect of root pruning at different timings throughout the year can cause a reduction in the potential uptake of nutrients from the soil until root regeneration increases the root volume. The subsequent result of this is to alter the relative uptake of nutrients between treatments depending upon timing of treatment, ease of uptake, availability in the soil solution and root regeneration.

Soil analysis for Cox shows that the winter and the petal fall root pruning treatments had lower quantities of potassium in the soil solution than the control whereas winter

+ petal fall and winter + July pruning treatments had greater quantities of potassium in the soil solution than the control for the 7th and 25th July sampling dates. This suggests that uptake has been reduced; however this assumption is not confirmed by the sap analysis. For the winter + petal fall, petal fall and July root pruning treatments calcium was present in far greater quantities than in the control for the 25th July, however this again does not correlate with sap analysis.

The soil solution under Conference showed a reduced level of potassium and magnesium but a drop on the 25th July in both cases is unexplained. In all cases the level of calcium was less than the control but again this is unexplained.

From the leaf analysis it can be seen that more nitrogen had accumulated in the Cox leaves for the winter + July treatment and that manganese, copper and zinc are seen to respond positively to each of the treatments. In the case of Conference, phosphorous, potassium and boron were reduced in the leaves for all root pruning treatments. Conversely magnesium, calcium, manganese, copper and zinc were all elevated in the leaves of Conference for all root pruning treatments. This was in contrast to previous work (Schupp and Ferree, 1989) where root pruning was shown to have no effect on leaf nutrient levels in apple. Other work on Fuji on M.26 (Dong *et al.*, 2003) has shown that root pruning reduces nitrogen uptake and that root regeneration to restore the root system to a similar functional and physical level to that of unpruned trees takes about 2 months.

The fruit analysis for Cox shows that iron has the greatest response to root pruning treatments. Nitrogen, phosphorous, potassium and magnesium levels are depressed in all treatments and calcium is increased in the winter + July and petal fall treatments. In Conference the levels of nitrogen and iron are depressed in all treatments and the levels of phosphorous are roughly that of the control. Levels of calcium are depressed in the winter + petal fall and petal fall treatments and elevated in the winter and July treatments.

There was no noticeable difference in the pest and disease status between treatments for either the Cox or the Conference. This supports previous findings (Schupp and

Ferree, 1989) where root pruning was shown to have no effect on pest or disease status.

The effects of root pruning on shoot growth were similar for both Cox and Conference. The single treatments in July had the least effect and appeared to stimulate growth in the Conference and in one of the Cox treatments. In Cox the most severe single treatment was at petal fall reducing growth by 23-26%. Winter + July gave a similar growth reduction and the winter treatment alone controlled growth by 14-16%. In Conference the most severe treatment was at petal fall reducing growth by 16-18%. The combined winter + petal fall or July increased the growth control by a further 6-10%. The reduction in shoot length concurs with previous results (Webster *et al.*, 2003) where root pruning has been shown to reduce extension growth severely in Queen Cox grown on M.9 rootstock. However in this previous work extension growth was affected to a greater extent but this was due to the younger age of the trees and severity of the treatment where the trees were root pruned at a distance of 22cm from the trunk in a circle around the base rather than down each side of the row. Work by other authors (Schupp and Ferree, 1989) has confirmed that a greater reduction in growth occurs as the distance decreases between root pruning blade and the trunk. The reduction in growth following root pruning has been reported to be due to an alteration in water status of the trees (Geisler and Ferre, 1984) rather than production of ethylene or an alteration in cytokinin levels.

There was no effect on shoot number in either the Cox or Conference from the root pruning treatments. This was however not an unexpected result for the first year of the trial. It was observed that there was a greater effect of position of the tree in the row than from the treatments applied. Work by Khan *et al.*, 1998, has shown a reduction in the number of shoots in the second year following root pruning for Braeburn, Royal Gala, Oregon Red Delicious, Splendour, Granny Smith and Fuji grown on MM.106 rootstock.

The July treatment has least effect on fruit size and the winter + petal fall treatment has the greatest reduction in fruit size for Cox. However for Conference, the winter treatment had positive effect on fruit size and the petal fall treatment has the greatest reduction in fruit size. It was also shown for Conference that the root pruning treatment conducted at 60cm depresses fruit size to a greater extent than the root pruning treatment conducted at 90cm. In previous work on Queen Cox (Webster *et al.*, 2003) root pruning was shown to increase cumulative yields of Class I fruits but in initial years of the experiment reduced the mean individual weights of fruits. In other studies (Schupp and Ferree, 1989) root pruning has been shown to have no effect on total yield but has been shown to reduce fruit size. It has since been concluded (McArtney and Belton, 1992; Brunner, 1990) that fruit size is reduced only when fruit numbers are high, possibly due to less root regeneration in trees carrying a heavy crop load.

The results of fruit number per tree indicated that there was no difference between treatments for either Cox or Conference.

Conclusions

Although there was no effect on flower number of fruit set in the first year previous work has indicated that flower number and fruit set may increase in subsequent years of root pruning treatments.

Sap analysis shows that root pruning affects nutrient uptake due to the removal of sites for nutrient uptake and the 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 causes nutrients to be taken up at differing rates.

As root removal can reduce potential sites of nutrient uptake, the soil solution from unpruned trees can contain less of the measured nutrients than soil from root pruned trees. However, after root pruning root regeneration occurs and regenerating roots have been shown to be more active in nutrient uptake than older roots. In addition to this the relative mobility of the nutrients in the soil solution must also be taken into account, along with the relative ease of uptake by the plant.

From the leaf analysis it can be seen that in Cox and Conference, nitrogen, manganese, copper and zinc are seen to respond positively to the root pruning treatments. These results are in contrast to previous work where root pruning was shown to have no effect on leaf nutrient levels or a reduction in nitrogen level in apple.

The fruit analysis shows a range of trends for mineral content for both Cox and Conference. However to interpret the sap, leaf fruit and soil solution results more fully and draw firm conclusions a second seasons data is required.

In the case of pest and disease status, there was no noticeable difference between treatments, which supports previous findings.

The effects of root pruning on shoot growth were similar for both Cox and Conference. The single treatments in July had the least effect and appeared to stimulate growth in Conference and Cox. In Cox and Conference the most severe single treatment was at petal fall reducing growth by 23-26% and 16-18% respectively. In Conference the combined winter + petal fall or July increased the growth control by a further 6-10%. The reduction in shoot length concurs with previous results.

There was no effect on shoot number in either the Cox or Conference from the root pruning treatments. This was however not an unexpected result for the first year of the trial as other research has shown treatment differences in the second year following root pruning.

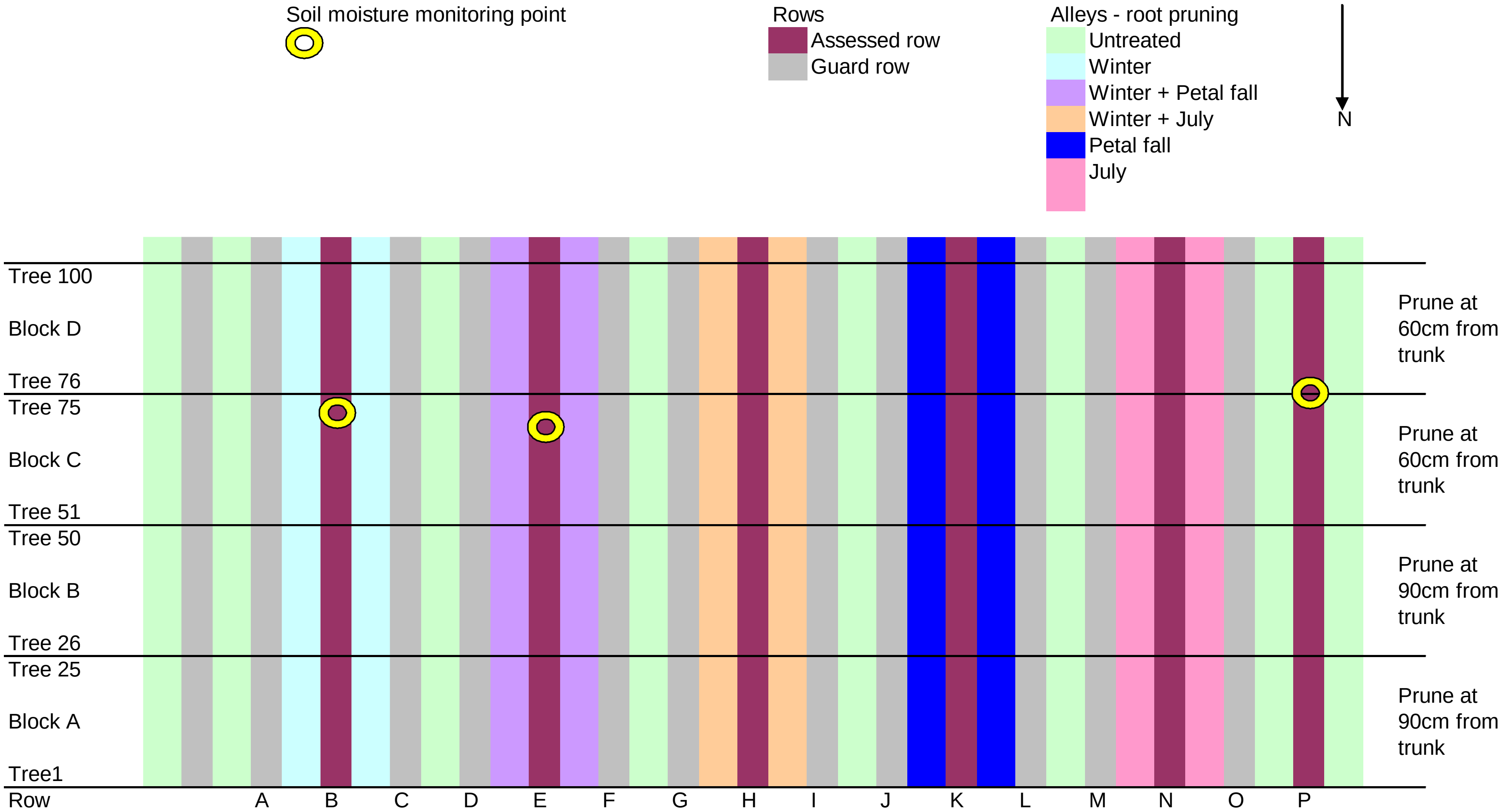
Fruit size was affected by the root pruning treatments with a greater reduction of average fruit size with the pruning treatments that are closer to the trunk of the tree. These results are supported by previous research. The timing of the treatments also had an effect on fruit size with the winter + petal fall application causing the greatest reduction in fruit size in Cox and the petal fall application causing the greatest reduction in fruit size in Conference. 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.

Although fruit size was affected by root pruning treatments the results of fruit number per tree indicated that there was no difference between treatments for either Cox or Conference.

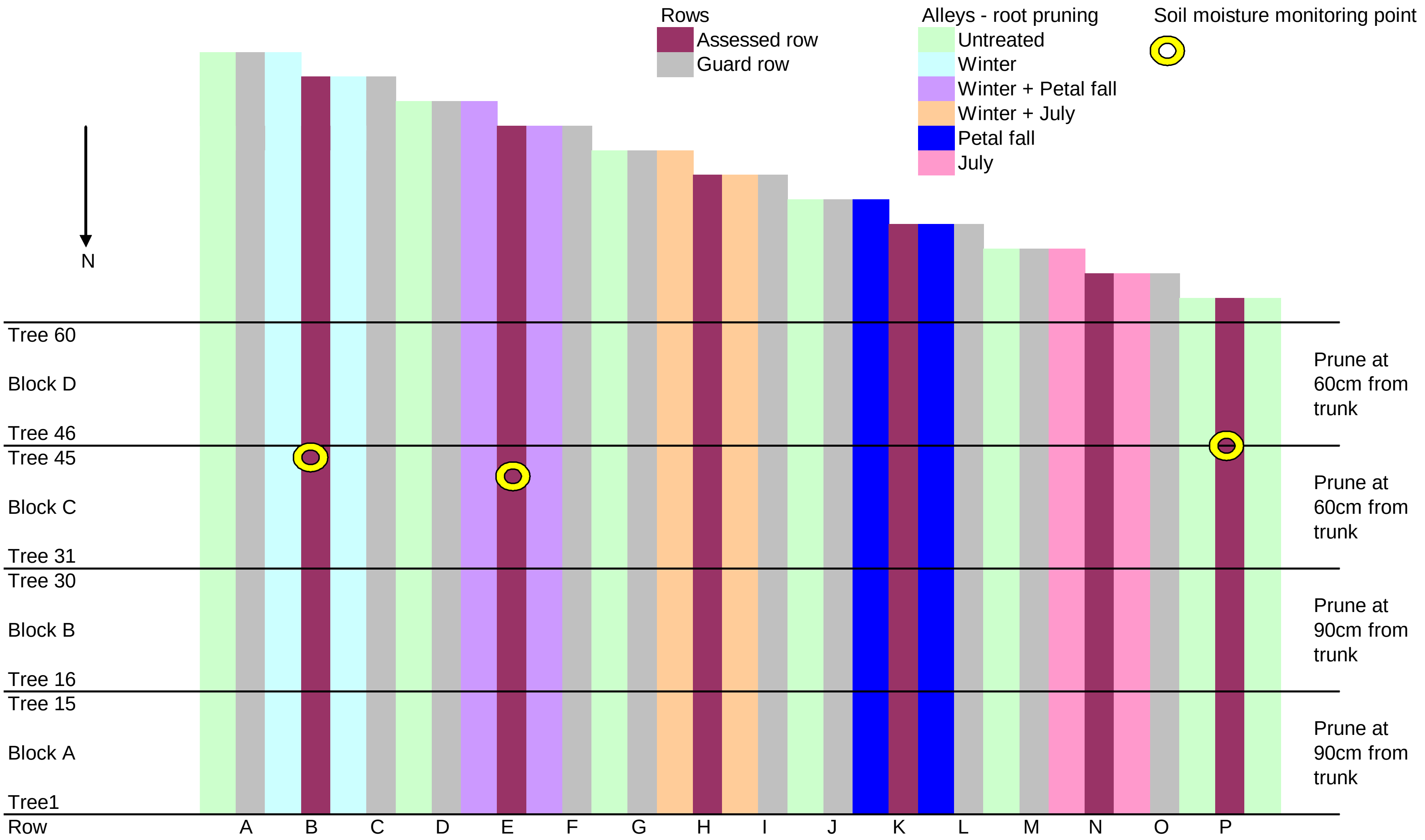
In summary, the first year of project TF 154 has shown that root pruning can be an effective tool for controlling the shoot growth of Cox and Conference. The distance of treatment application from the trunk and timing of application have been shown to be critical in shoot regeneration but to also have an effect on fruit size. Root pruning has also been shown to have an effect on nutrient uptake and further investigation is required in the second and third years of this project.

Appendix I.

Trial layout: Cox



Trial layout: Conference



Appendix II.

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