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DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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GROWER SUMMARY

Headline

- Higher yields were achieved from hand pruning treatments than from mechanically pruned treatments in this fruit wall pruning trial, although labour savings are available from integrated use of mechanical pruning.

Background and expected deliverables

Apple growers are continually trying to reduce labour costs in their production systems to remain commercially viable, whilst aiming to increase yield and improve fruit quality. The fruit wall production system, where pruning can be carried out in part using hedge type cutters, is one possible solution. Research into mechanical pruning of fruit walls has already been done in mainland Europe and particularly in Belgium and France, where the concept of fruit walls originated. However, the positive recommendations developed there need to be assessed and adapted in other countries and regions where growing conditions and varieties differ.

The exact timing of the pruning cut determines the amount of vegetative regrowth and also whether the bud behind the cut becomes floral or remains vegetative. Determining the optimum time to make the pruning cut will help to achieve maximum productivity from the fruit wall system.

This trial was set up to determine the optimum time to mechanically prune orchards planted as a fruit wall, compared to a winter hand pruned control. The effects of inter pruning versus non-inter pruning were also examined. The trial was conducted over five years to assess the long term effects of the treatments.

Summary of the project and main conclusions

The trial was established in 2012 in an existing high density commercial orchard of the apple variety Gala (Galaxy clone), planted in the winter of 2009/10 on a clay loam soil at Parsonage Farm, Cobham, Kent, by kind permission of Adrian Scripps Ltd.

The trees were trained on a post and wire system with bamboo cane supports at a planting distance of 3.5 x 0.5m (5,714 trees per hectare) with 10 trees between each post, forming a bay, and each plot consisting of two bays. The trial area comprised 800 trees in 20 bays of 10 trees in each of four blocks. Each plot consisted of 20 trees: 6 guard trees at each end and 8 trees used for sampling and recording.

Conventional winter hand-pruning was compared with mechanical pruning using a tractor mounted cutter bar, at four different growth stages; pink bud and when extension growth had

produced 6, 9 or 12 new leaves (or when 50% terminal buds were present). Each of these treatments was carried out either with or without inter-tree hand-pruning, which was done at the same time as the winter pruning treatment. Mechanical pruning began in 2012 and finished in 2016, with the first inter-tree pruning starting in 2012/13 and concluding in 2015/16.

Results for 2016

As in previous years, the winter and early season cuts produced the strongest regrowth (approximately 35cm) and the latest timing the least regrowth (approximately 11cm). Later cuts controlled growth better.

Yields were lower in 2016 and there were statistically significant differences between the treatments but the Winter Hand control still had the highest cumulative yield. Cumulative yield was reduced for later pruned treatments, except for 9 Leaf Non Inter Pruned (NIP).

Over 85% Class 1 was recorded for all treatments except 6 Leaf Inter Pruned (IP) and was highest for Winter NIP. IP lowered Class 1 percentage except for 9 and 12 Leaf.

Small increases in fruit size/weight were again recorded in the IP plots and results were statistically significant but fruit size and weight were generally reduced in 2016.

Fruit colour was poor in 2016. Later NIP treatments significantly improved colour. However, from the sub sample of fruit assessed, only Winter Hand IP, 6 Leaf NIP, 9 Leaf NIP and 12 Leaf NIP had an average of above 60% red colour.

There were no significant differences in maturity (starch) at harvest.

BRIX^{o} levels for all treatments in 2016 were >12 at harvest (when average starch was 90-95%). There was a significant reduction of fruit sugar levels in the later summer cuts.

Fruit firmness values between treatments were very similar.

There were no significant differences between treatments for leaf or fruit nitrogen, but levels in earlier mechanically pruned plots were higher than the later cuts.

Lower than average rainfall from July to October, higher than average temperatures in August and September and high night time temperatures leading up to harvest may have contributed to the lower yields, smaller fruit size and poor colour in 2016.

A more comprehensive report of the results of the 2016 season can be read in the Science Section of this report.

Overall results and conclusions from the whole project 2012 – 2016

Pruning timing

Pruning dates varied considerably between 2012 and 2016 depending on the earliness of the season. The number of days between pink bud and the 12 leaf stage varied from 55 days in 2016 to 68 days in 2013.

Vegetative regrowth

In every year of the trial, the later pruned treatments had significantly less regrowth. After 2014, a trend developed where the shoot growth in the non-inter pruned (NIP) was significantly shorter than the inter pruned (IP).

Yield per tree

There were significant differences for average yield per tree in three of the five years recorded. NIP trees were displaying higher yields towards the end of the trial.

The Winter Hand Pruned NIP produced the highest yields in every year recorded, but by 2016, the Pink Bud IP, Pink Bud NIP and 9 leaf NIP treatments had statistically similar yields to the Winter Hand Pruned IP treatment.

Yield per hectare

The Winter Hand Pruned NIP treatment had the highest cumulative yield over the trial followed by the Winter Hand Pruned IP and Pink Bud NIP. Both Winter Hand treatments yielded more Class 1 fruit than any other treatments (Figure 1).

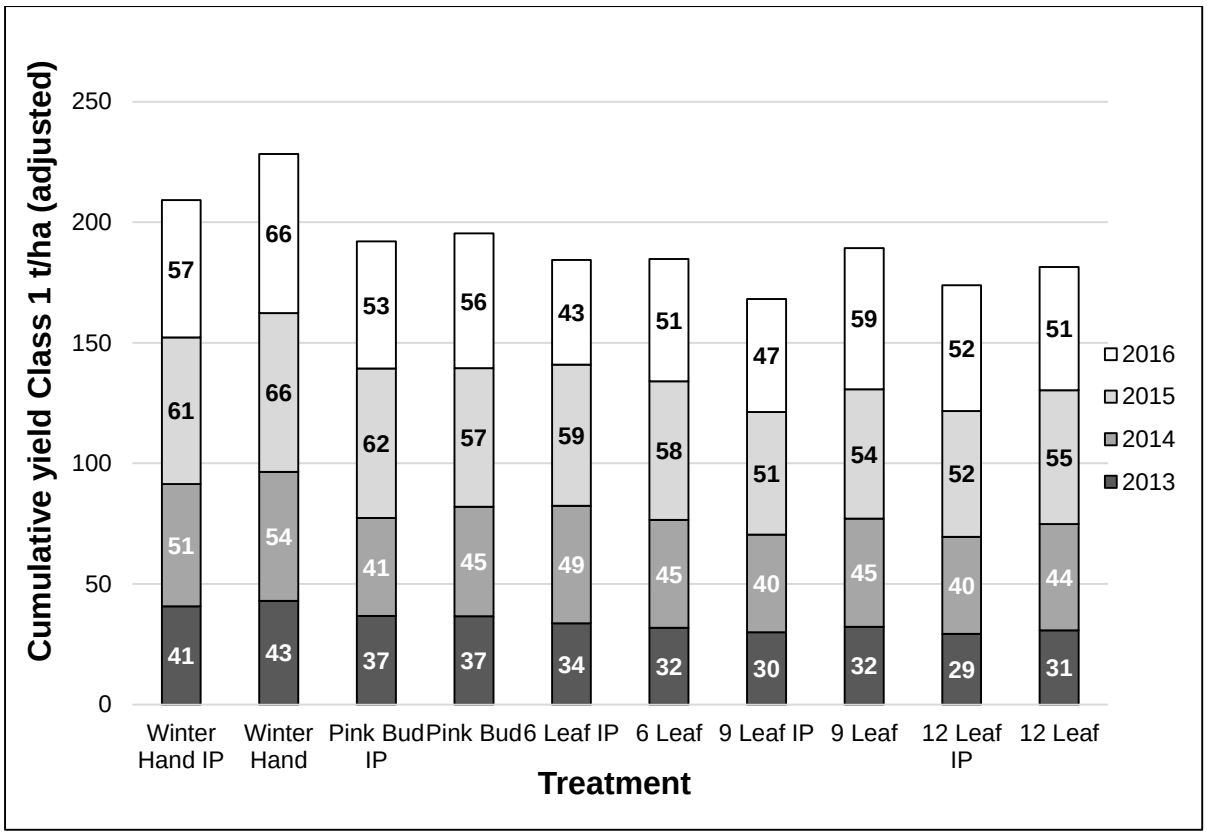


Figure 1. The effect of pruning treatments on cumulative yield per treatment – Class 1 t/ha adjusted for % pollinators and diseased trees within trial section of the orchard.

Fruit weight and diameter

There were only significant effects of treatment on fruit weight and diameter in 2013, 2014 and 2016. In 2013 and 2014, the later pruned and inter pruned treatments produced larger fruit.

Fruit colour

All pruning treatments had sufficient colour to meet Class 1 standards in every year except 2016.

Fruit quality and maturity

There were no statistical differences in fruit starch levels between treatments in any year of the trial. Fruit sugar content was below BRIX^{o} 12 for all treatments in every year apart from 2012. This is below the commercially acceptable standard. Although there were significant differences in sugar content in every year, the results showed no consistency.

Fruit firmness

There were no significant effects on fruit pressure in any year of the trial except in 2012, when Pink Bud had statistically higher pressure than any other treatment.

Mineral analysis

Mineral analysis on fruit was conducted in 2012, 2013 and 2014. The only significant difference between treatments occurred in 2014 when significantly higher P levels were noted in the Pink Bud IP treatment. The mineral levels were adequate for long term storage until April.

Leaf analysis

Leaf analyses were conducted in every year from 2013 until 2016. There were significant differences in every year between treatments but these were not consistent from year to year. In 2015 and 2016, a trend showing higher leaf nitrogen in Winter Hand Pruned and earlier mechanical cut treatments developed, but these were not significant.

Fruit dry matter

Dry matter content (DMC) was only measured in 2015 and 2016. The only significant differences were found in 2016, where the Winter Hand, Pink Bud and IP sub treatments had higher dry matter. All treatments had above 12% DMC.

Conclusions

- New intensive orchard systems are simpler, easier and cost less to prune than lower density traditional orchards. Irrigation is critical at high planting densities otherwise fruit size and quality may deteriorate.
- Winter Hand treatments continuously had higher yields than any mechanical cutting treatment although Pink Bud and 9 Leaf NIP were similar alternatives. The trial orchard was not vigorous and it should be noted that differences in growth response and yield could be much greater in orchards that are stronger.
- Percentage of Class 1 fruit was acceptable in all years.
- Starch and fruit firmness were not affected by any of the treatments and dry matter accumulation was acceptable in the two years tested. BRIX^0 levels were generally low in all years but it should be noted that fruit in the trials section was harvested earlier than the rest of the orchard and sugars would improve in store.
- Varying levels of leaf and fruit minerals (from analyses) did not appear to have any detrimental effect on treatments.
- Over the period of the trial, as the trees responded to the mechanically pruned treatments, more fruiting wood developed and the trees became better furnished resulting in increased cropping within the narrower tree canopy. It should be noted that cumulative yields were still highest at the end of the trial in the hand pruned trees.

- Inter-tree pruning generally led to slightly more growth and lower yields.
- It is important to judge when to prune by a definitive growth stage rather than by a calendar date. Growers and their staff must assess trees and orchards each year and understand the implications of the degree and the timing of pruning management, in terms of effects on yield, growth and fruit bud development. The timing of mechanical pruning should be based on the needs of the orchard rather than pruning at a prescribed time each season.
- In strongly growing orchards and where tree vigour control is important, it could be better to delay mechanical pruning to the 9 or 12-leaf stage.
- Where limited regrowth and improved fruit bud formation are required, pruning at the 9-leaf stage appears to be best.
- Where trees are not vigorous and are in balance, pruning at Pink Bud may benefit fruit size and sugar content, but this will encourage more growth.
- Growers will need to weigh up the benefits of the increased cumulative yield from winter hand pruning early in the life of a fruit wall against any labour savings from mechanical pruning.
- Further work may be useful in order to assess how to further adapt, develop and implement mechanical pruning as part of a husbandry management programme and to test it on other varieties.

Financial benefits

The harvest in 2016 was the fifth picked from the orchard planted in the winter of 2009/2010. Annual yields in the commercial orchard have followed the expected levels of an establishing Gala crop in the UK (ie.50 t/ha by year 7). The yields in 2016 were lower than those in 2015 in every treatment except 9 Leaf NIP.

At the planting distance of trees in this trial (0.5m) it would take approximately 46 hours (7.5 days) to hand prune one hectare of orchard (FAST 2017) compared to three hours for mechanical pruning (Adrian Scripps Ltd 2017). Mechanical pruning therefore offers a labour saving of 43 hours per hectare.

At the planting density of the orchard in this trial (5,714 trees/ha) the total commercial cost of pruning would be around £451 per hectare (approximately £0.08 per tree to mechanically cut and for inter and top pruning by hand (Adrian Scripps Ltd 2017). Realistically, trees would not be planted at this spacing unless specifically for fruit wall management – at such high densities orchards can only be machine pruned. Therefore, financial comparison must be made with a lower density orchard (eg. 2,575 tree/ha) where the commercial cost of hand pruning trees

would be £515 per hectare (£0.20 per tree for base and top pruning by hand – Adrian Scripps Ltd 2017). A saving of £64 per hectare could be made on pruning costs for a fruit wall managed orchard.

For growers to implement mechanical pruning, they would have to rent or buy specialist pruning machinery. Current costs for this type of equipment are approximately £16,750 (Seymour 2017), but the machine could also be used for other operations on the farm such as hedge and windbreak cutting and pruning the tops of conventional hand pruned plots. It could also be rented out or shared with other local growers.

Anecdotal evidence from experimental plots in Northern Europe suggested that annual yields from fruit wall plantings could yield around 20 t/ha more than orchards of a similar density managed conventionally. However, in Poland, Mika et al (2016) have recorded only an 11.5% increase in yields from mechanically pruned compared to hand pruned trees which would equate to, for example, 50 t/ha versus 45 t/ha respectively. Conversely, a reduction in yield of 5% from a fruit wall system in each of the first four cropping years can reduce net returns.

In this AHDB trial, during the first five cropping years, the Class 1 yield reductions in the mechanically pruned treatments compared to hand pruned were much larger than the 5% originally expected. Reductions from 16% (Pink Bud) to as much as 26% (9 Leaf IP) were recorded (see Table 1). These yield losses are considerable and undermine the financial viability of the fruit wall model used in this trial, despite the (minimal) reduction in pruning costs.

The yields of all mechanically pruned treatments remained lower than the standard winter pruned plots in each year of the trial and the yield gap has shown no consistent or substantial signs of closing (except for Pink Bud NIP which had the lowest total % loss). For example, the yield reduction for 6 Leaf IP compared to Winter Hand NIP was -22% in 2013, -9% in 2014 but -34% in 2016. Similarly, Pink Bud IP was -24% in 2014, -6% in 2015 but -20% in 2016.

It must be noted that these yield reductions may well be due to the rigid timings of the fruit wall cuts set out in the trial protocol and followed every year. In reality, a grower would have the flexibility to accurately time any fruit wall cut based on the needs of the orchard and depending on the seasonal conditions rather than mechanically pruning every year at a prescribed time (eg every year at pink bud or at a certain leaf stage) or alternatively decide not to prune at all in a season or only conduct inter pruning, if appropriate. Therefore cropping potential may well be enhanced if fruit wall cuts were timed carefully to the actual needs and growth rates of the orchard. Therefore, any yield reductions of orchards managed using fruit wall methods as part of a bespoke husbandry programme compared to conventionally pruned orchards could be decreased or negated and financial benefits enhanced.

Table 1. Percentage Class 1 yield reduction (compared to Winter Hand) per treatment per year and total over 5 years.

Treatment/Year	2010	2011	2012	2013	2014	2015	2016	Total
Winter Hand IP	0%	0%	0%	-5%	-5%	-8%	-14%	-7%
Winter Hand	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Pink Bud IP	0%	0%	-26%	-14%	-24%	-6%	-20%	-17%
Pink Bud	0%	0%	-26%	-15%	-15%	-13%	-15%	-16%
6 Leaf IP	0%	0%	-20%	-22%	-9%	-11%	-34%	-19%
6 Leaf	0%	0%	-20%	-26%	-17%	-13%	-23%	-19%
9 Leaf IP	0%	0%	-23%	-30%	-25%	-23%	-29%	-26%
9 Leaf	0%	0%	-23%	-25%	-16%	-19%	-11%	-18%
12 Leaf IP	0%	0%	-33%	-32%	-25%	-21%	-21%	-25%
12 Leaf	0%	0%	-33%	-28%	-18%	-16%	-23%	-22%

Action points for growers

2016 Results

- It is important for growers to assess their orchards and trees before deciding on the timing of pruning.
- Where tree control is the major consideration delayed pruning is advised.
- Whilst in 2016 Winter Hand produced the highest yields, for Fruit Wall management the 9 Leaf NIP appears to be the optimum Fruit Wall timing (highest yields and best grade out compared to other timings in 2016).
- Where improved fruit size is required, inter pruned trees have an advantage.
- For improved colour later cuts without inter pruning appear to be the optimum.
- Adequate irrigation and consideration of colour improving products in high risk years should be considered to maintain size and quality.
- Amelioration for low P, K, Ca and Mn may be required if choosing to prune after Pink Bud.

Whole trial results

- Mechanical pruning could be a valuable alternative management tool when employed as part of a customised husbandry programme.
- Mechanical pruning can be used instead of hand pruning in years where time is limited, labour shortages occur, where there are prolonged poor or challenging weather conditions and as an occasional cost saving exercise.
- Growers must assess their orchards for quantity, quality and position of fruit bud, growth habit and shade and consider their requirements before deciding whether and when to mechanically prune.
- Growers may consider mechanically pruning at different growth stages each year according to the orchard's vigour and needs (and as advised by their agronomist).
- Growers need to regularly make random leaf counts on current season's extension to establish the optimum growth stage before any mechanical pruning.
- Inter tree pruning requirements should be considered and will need to be done regularly once new orchards reach maturity and for converted orchards. Only one or two cuts per tree may be required.
- Irrigation is critical at high planting densities otherwise fruit size and quality may deteriorate. Growers will need to ensure adequate irrigation especially during low rainfall / higher than average temperature seasons to ensure adequate fruit size and maintain sufficient regrowth. Extra fertigation and mulching should also be considered in particular for any weak areas.

- Growers should take regular leaf samples and be prepared to apply some foliar feed for micro and macro nutrients as required including amelioration for low P, K, Ca and Mn if choosing to prune after early cuts.
- Later mechanical pruning may reduce BRIX^0 and dry matter which will need to be considered by growers with low BRIX^0 / dry matter orchards planning on using the system as part of their pruning strategy.
- The narrow profile of mechanically pruned orchards may be suited to narrower alleyways. Growers may consider increasing the density and trees per hectare for newly planted orchards and maximise the yield efficiency of orchards managed under the Fruit Wall system as part of an integrated approach.

SCIENCE SECTION

Introduction

Growers in many countries are actively looking for ways to reduce labour inputs and increase mechanisation in a range of fruit crops. The fruit wall concept originated in France in 1986 when CTIFL began a project which aimed to reduce growing costs in top fruit production. Around the same time a harvesting robot known as the Magali was developed and CTIFL adapted an orchard to create a narrow tall hedgerow (the fruit wall) to accommodate the robot and maximise the use of automation at harvest. As a result the work by CTIFL demonstrated the potential of the fruit wall growing system in reducing the costs associated with hand pruning and increasing Class I yields. However, differences in cropping were shown between the south and north of France with the trial plots in the north performing less well than in the south.

The fruit wall system was being considered as an option for commercial practice in the UK, as mechanisation of pruning and other operations, for example thinning, became possible but required a modified tree architecture to be successful. Results from the original work by CTIFL in France can be applied to growing areas further north, but only by adapting the methods, particularly the time of pruning, to the local growing conditions.

Three key factors influence total productivity from a fruit wall orchard:

- Planting density
- Tree architecture
- The timing of pruning

These factors all have an effect on extension growth, flower bud initiation and yield by influencing light interception and distribution by and through the canopy and the total amount of fruiting wood in the orchard. The management of these factors determines whether the fruit wall is able to provide increased and sustainable yields throughout the life of the orchard.

Hampson *et al* (2002) demonstrated that planting density can have a greater influence on productivity than the training system (tree height and shape). Trees planted at lower density were more productive per tree than at a higher planting density due to reduced competition for resources, however higher planting densities tend to be more productive per hectare. Palmer *et al* (1992) suggest that Leaf Area Index (LAI) increases with increased planting density with greater overall light interception as a result. Higher planting density systems tend to increase yields per unit area through more efficient use of ground area until a natural limit

is reached (Weber 2001). For the fruit wall system to achieve greater productivity it should make improved use of the unit ground area than traditional orchard system designs.

Hampson *et al* (2004) demonstrated in their study that the percentage of fruit with acceptable colour was reduced with increased planting densities. Red colouration is an important fruit quality attribute and, therefore, as planting density increases the percentage of Class I fruit may become compromised. The tree architecture of the fruit wall system has the potential to overcome issues such as reduced red colouration, as the trees tend to be narrower than in traditional orchards and result in less shading of the fruit. It is essential to maintain the narrow shape and size of the trees composing the fruit wall to maximise the light distribution throughout the tree. In the fruit wall system, a pruning cut is made by a tractor mounted mechanical cutter bar during the summer rather than in the winter to create an A shaped tree which is 40cm wide at the top and 80cm wide at the base.

However, the aim of pruning is not only to achieve the narrow 'A' shape trees but also to encourage flower bud formation. Flower bud formation usually occurs during August (Abbot 1974; cited in Dennis 2003) and so conditions prior to this are important in determining its extent. There tends to be negative correlation between vegetative growth and flower bud formation. Pruning treatments and management inputs e.g. nitrogen applications which favour vegetative growth tend to reduce flower bud formation whereas plant growth regulators (PGRs) which retard vegetative growth tend to improve flower bud formation. In the Fruit Wall system, the pruning cut is made during the summer and the timing of the cut is critical in determining the amount of vegetative regrowth and flower bud formation. This is also true for other crops such as cherry since Guimond *et al* (1998) showed that flower initiation was stimulated by summer pruning and vegetative growth also increased due to the removal of apical dominance along the shoot. If the Fruit Wall cut is made too early then vegetative growth will be favoured, reducing flower bud formation. However, if the cut is made too late the flower buds will have already formed and the cut will simply remove them. The optimal date for the Fruit Wall cut to be made may vary between varieties and between different seasons. Therefore it is essential to relate the time of the cuts to an easily identified growth stage.

With mechanical pruning the branches in between the trees are left unpruned and these can become thick and intertwined resulting in shading and adverse effects on fruit quality. It is important for growers to know the effect, if any, of removing these branches on yield and fruit quality.

The aim of the trial was to determine the optimum time for mechanical pruning Gala (clone Galaxy) in a Fruit Wall system and to evaluate the effect of inter tree pruning. The results

from 2016 are presented in this report, together with the cumulative yields from the previous four years, a summary of the results from 2012 to 2016 including adjusted cumulative yields, plus completion of objectives, technology transfer recap and final conclusions.

Materials and methods

The trial was based in an existing commercial orchard of *Gala Galaxy* planted in the winter of 2009/2010 at Parsonage Farm, Cobham, Kent, on a clay loam soil. The trees were trained on a post and wire system with bamboo cane supports at a planting distance of 3.5 x 0.5m (5714 trees per hectare) with 10 trees between each post, forming a bay, and each plot consisting of two bays. The trial area comprised of 800 trees in 20 bays of 10 trees in each of 4 blocks – see Table 2 below.

Table 2. Plot layout and treatment number.

Block 1	Block 2	Block 3	Block 4
7	3	2	5
1	8	4	7
4	9	5	10
8	10	6	1
2	5	3	9
6	1	7	8
5	2	10	3
3	4	9	6
10	7	8	2
9	6	1	4

The trial was a randomized complete block design with the 10 treatments replicated in 4 blocks. The treatments consisted of 5 different pruning timings each of which had 2 sub-treatments with either inter tree pruning (IP) or no inter tree pruning (NIP). Each plot was composed of 20 trees: 6 guard trees at each end and 8 trees used for sampling and recording:

6 guard trees	**8 trees used for recording**	**6 guard trees**

Treatments

A description of the treatments is shown in Table 3 below. Each treatment consists of two elements: (a) the timing of the pruning cut and (b) Inter Pruning (IP) or No Inter Pruning (NIP). The pruning cut was made by a tractor mounted mechanical cutter bar (with the exception of the Winter Hand treatments). The earliest mechanical cut treatment was made at Pink Bud (Treatments 3 and 4). See Figure 2 for average number of leaves and Table 4 for Fruit Wall cut timings. The later mechanical cuts were made when the new extension growth had

produced 6, 9 or 12 new leaves (Treatments 5 and 6, 7 and 8, and 9 and 10). The method of counting leaves to determine these stages is shown in Photograph 1.

Inter tree pruning treatments were carried out from winter 2012/13 and in subsequent years at the same time as the winter pruning treatment. The treatment consisted of removing one or two excessively strong, upright or long branches on each side of the tree which were causing shade. Any very weak or low branches were also removed.

Table 3. Treatment numbers and names and description of pruning timing.

Treatment number	Treatment name - timing of pruning	Sub treatment
1	Winter (by hand)	Inter tree pruning
2		No inter tree pruning
3	Pink bud	Inter tree pruning
4		No inter tree pruning
5	6 new leaf stage	Inter tree pruning
6		No inter tree pruning
7	9 new leaf stage	Inter tree pruning
8		No inter tree pruning
9	12 new leaf stage	Inter tree pruning
10		No inter tree pruning

Fruit wall cut timings

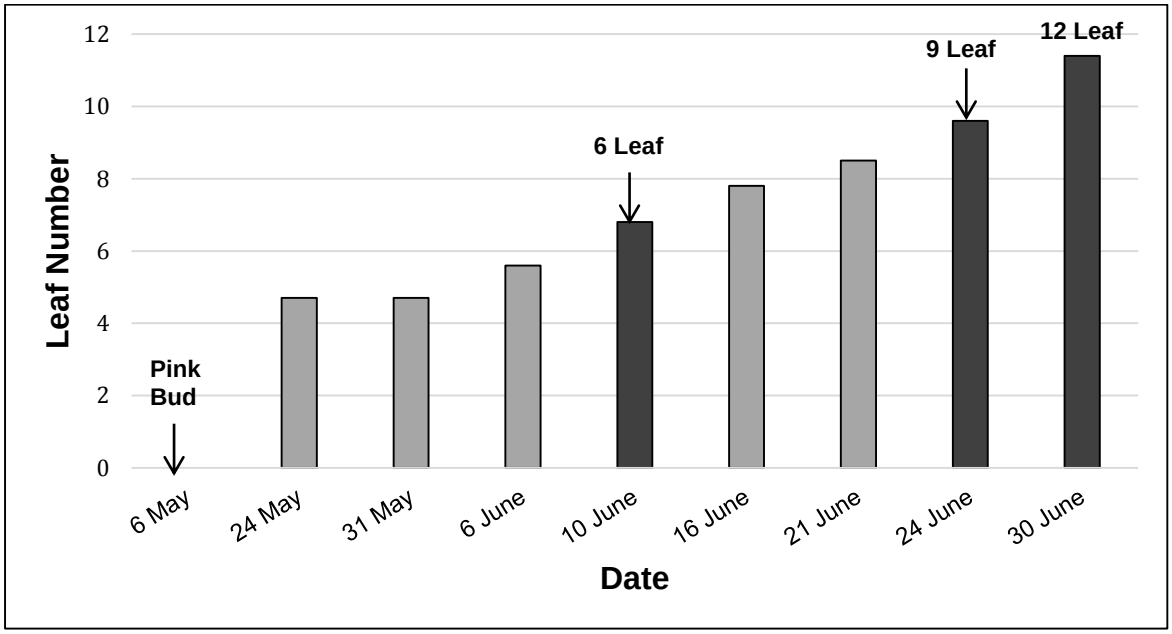
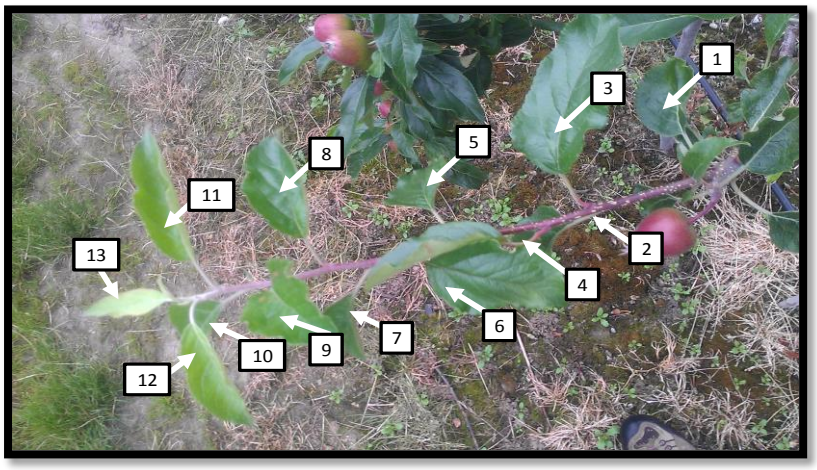


Figure 2. Average number of new leaves and timings of pruning cuts in 2016.

Table 4. Growth stage and dates of the pruning treatments in 2016.

Date	Number of leaves	Treatment
11 March		Inter Tree Pruning
6 May	0	Pink Bud
24 May	4.7	
31 May	4.7	
6 June	5.6	
10 June	6.8	6 Leaf
16 June	7.8	
21 June	8.5	
24 June	9.6	9 Leaf
30 June	11.4	12 Leaf



Photograph 1. New growth showing the number of fully expanded leaves. Note that the basal whorl of small leaves are ignored.

Assessments

1. Counting the number of new leaves produced on 25 shoots per plot commenced on 6 May 2016 and continued weekly from 25 May until 30 June when growth ceased. The average number of leaves per shoot was calculated to determine the timing of the cuts.

2. The length of new extension growth and number of leaves produced on the shoots arising from the bud immediately behind the pruning cut were recorded on 30 August and 30 October 2016. Where no mechanical cut was made (Winter Hand pruning) the current season's growth was recorded.

3. The effect of treatments on leaf mineral content was determined from samples taken on 31 August 2016. One leaf was selected from two thirds along the length of 25 extension shoots per plot.

4. Fruit dry matter was assessed from samples taken on 13 September when 25 fruits were selected at random from the guard trees in each plot.
5. Fruit was sampled at random from the middle 8 trees on 13 September for assessments and the following ascertained:
   - Average fruit weight (g), fruit diameter (mm), percentage Class and percentage red colour of 100 fruits or a sub sample from each plot.
   - Fruit quality and maturity from 10 fruits per plot, using the same methodology as the UK Quality Fruit Group to assess the percentage starch, flesh firmness and BRIXº.
6. Fruit was harvested on 14 and 15 September at commencement of the commercial harvest (actual harvest of the remaining orchard was undertaken on 22 and 23 September). The total yield from the 8 experimental trees in each plot ascertained.

Statistical Analysis

Statistical analysis of the data was carried out using Analysis of Variance (ANOVA) to determine any statistical significance between individual treatments. Where data was not normally distributed, such as in a percentage score assessment, the data was transformed using a logit transformation prior to analysis. Where statistical significance was evident Multiple Range Tests (MRTs) were conducted and the results of such tests labelled as homogenous groups indicating which treatments were significantly different. Charts are shown with standard error bars, where applicable.

Results

Vegetative regrowth

There were statistically significant differences in shoot length on both assessment dates (30 August and 30 October) between some treatments and some sub treatments (see Figures 3 and 5). Unlike 2015, shoot lengths were significantly shorter for Pink Bud compared to Winter Hand. Both 12 Leaf treatments only produced 11cm to 12cm of new growth compared to over 35cm for Winter Hand IP when measured in October.

There were no statistically significant differences in leaf number on 30 August (P=0.9177) but there were on 30 October between some treatments and some sub treatments when leaf number was significantly higher for Winter Hand (IP and NIP) compared to all other treatments. Leaf number was lowest for 12 Leaf. See Figures 4 and 6.

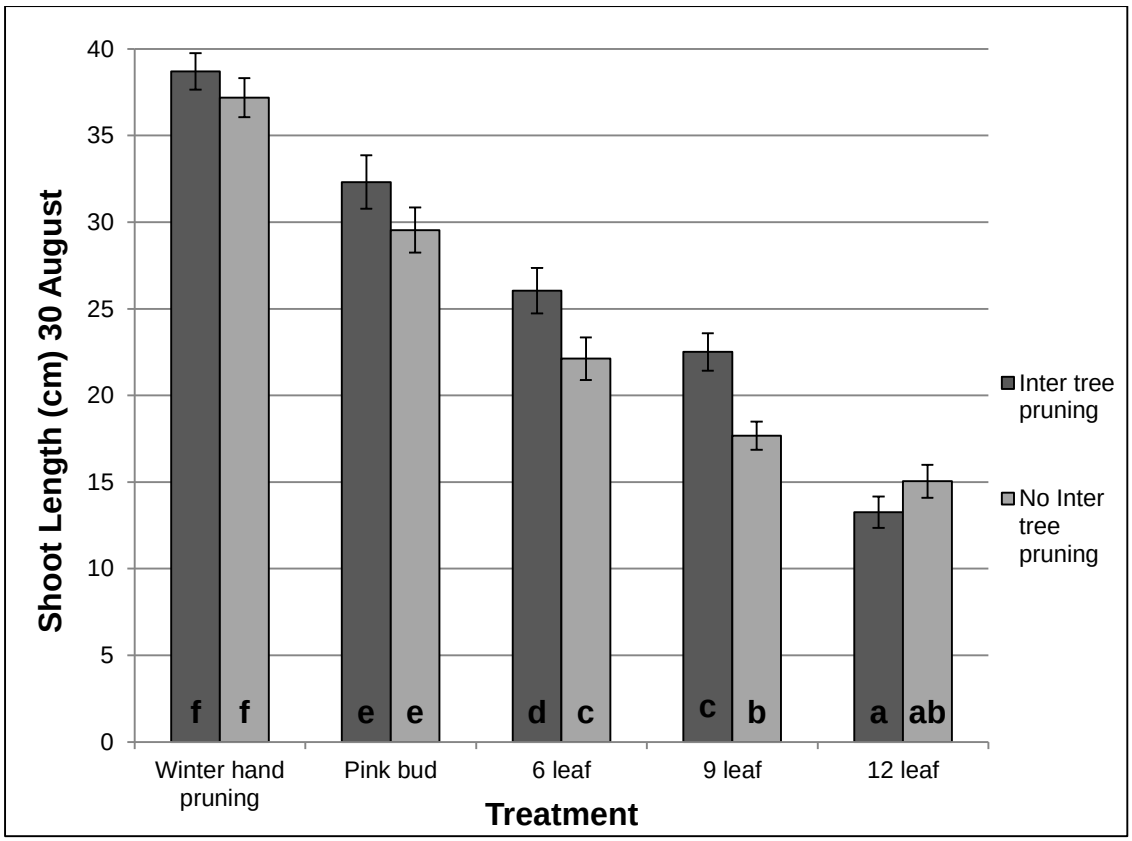


Figure 3. The effect of the pruning treatment on the extension growth arising from the bud behind the pruning cut (assessed 30 August). Statistical Multiple Range Test results sharing the same letter are not significantly different (P<0.0000).

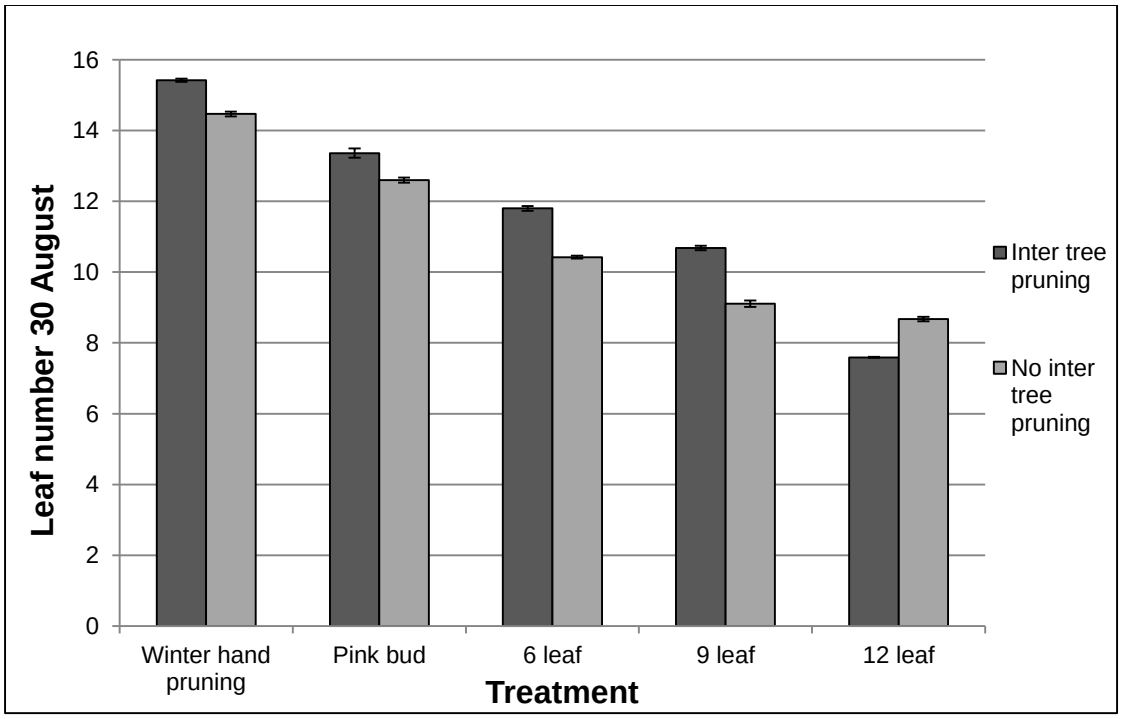


Figure 4. The effect of the pruning treatment on the number of leaves arising from the bud behind the pruning cut (assessed 30 August).

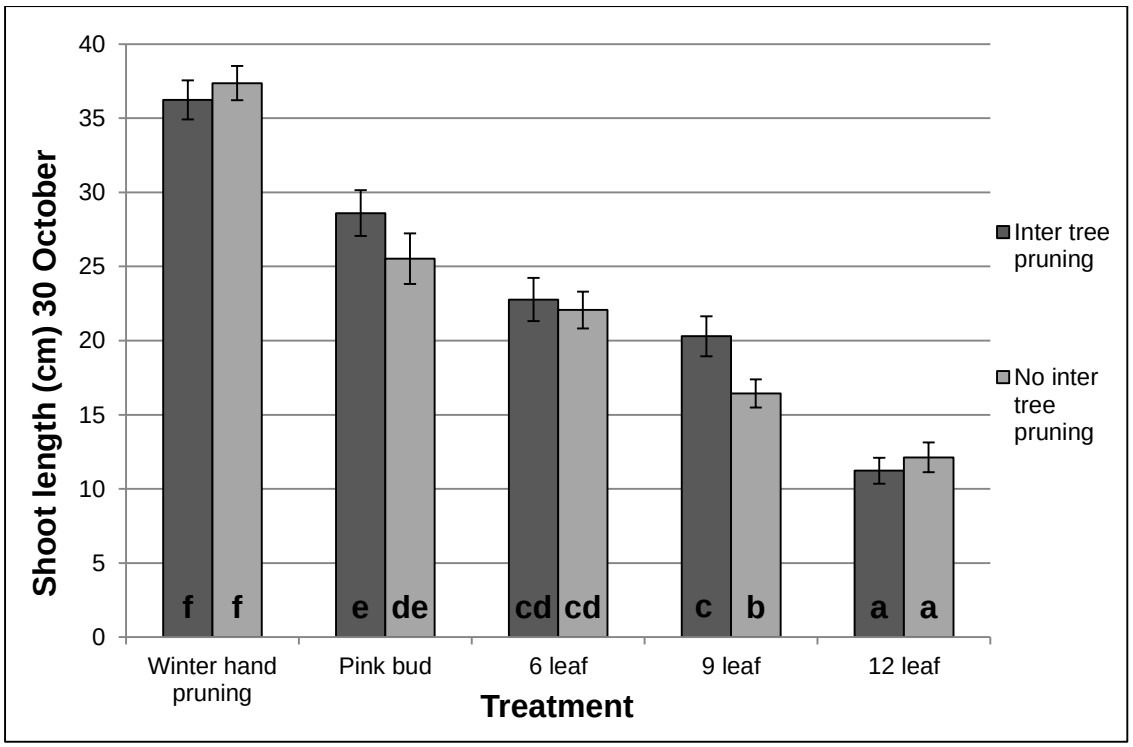


Figure 5. The effect of the pruning treatment on the extension growth arising from the bud behind the pruning cut (assessed 30 October). Statistical Multiple Range Test results sharing the same letter are not significantly different (P<0.0000).

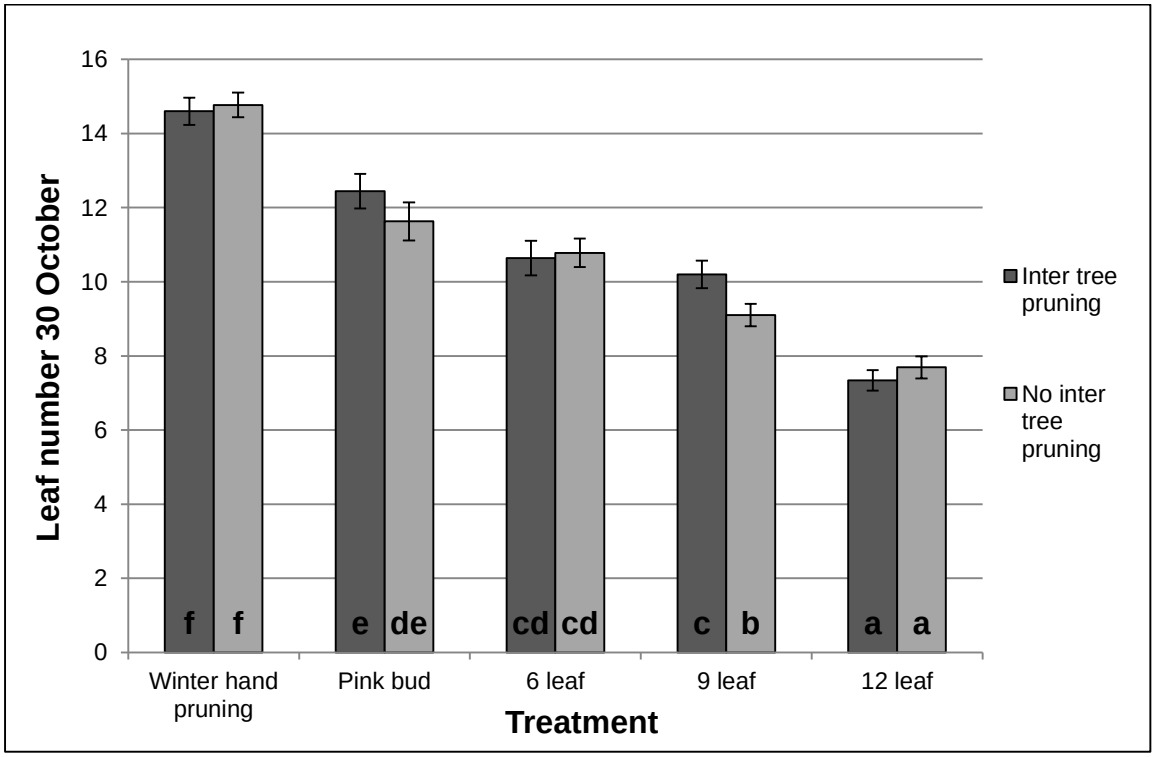


Figure 6. The effect of the pruning treatment on the number of leaves arising from the bud behind the pruning cut (assessed 30 October). Statistical Multiple Range Test results sharing the same letter are not significantly different (P<0.0000).

Yield

In 2016 total mean yields per tree varied between 14.62kg (Winter Hand NIP) and 10.46 kg (9 Leaf IP). Yields were significantly higher for Winter Hand NIP compared to all other treatments and sub treatments. 9 Leaf IP trees had significantly lower yields than any other treatment or sub treatment except for 6 Leaf IP. See Figure 7.

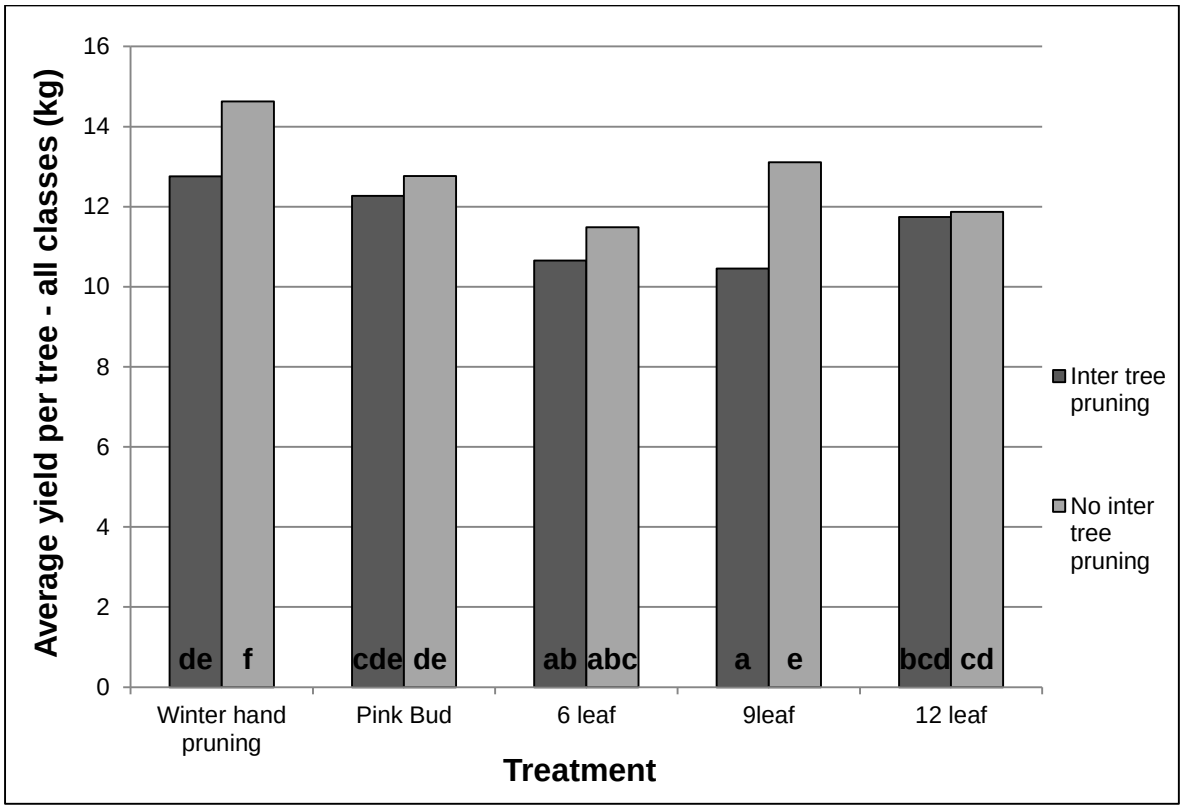


Figure 7. The effect of pruning treatments on the average yield per tree in 2016. Statistical Multiple Range Test results sharing the same letter are not significantly different (P<0.0000).

Cumulative Yield

Cumulative yields per tree for 2012 to 2016 (excluding sub treatments) varied between 58.1kg (Winter Hand) and 48.0kg (12 Leaf) (see Figure 8).

Cumulative yields per tree (all classes (kg) including sub treatments) between 2013 and 2016 varied between 52.8 for Winter Hand NIP (significantly higher than all other treatments) and 40.8kg for 9 Leaf IP (significantly lower than all other treatments). See Figure 9.

Total Cumulative Yields (t/ha combined) between 2013 and 2016 varied between 332 t/ha (Winter Hand) and 274 t/ha (12 Leaf) (see Figure 10).

Total Cumulative Yields (t/ha including sub treatments) between 2013 and 2016 varied between 301 t/ha (Winter Hand NIP) and 233 t/ha (9 Leaf IP) (see Figure 11).

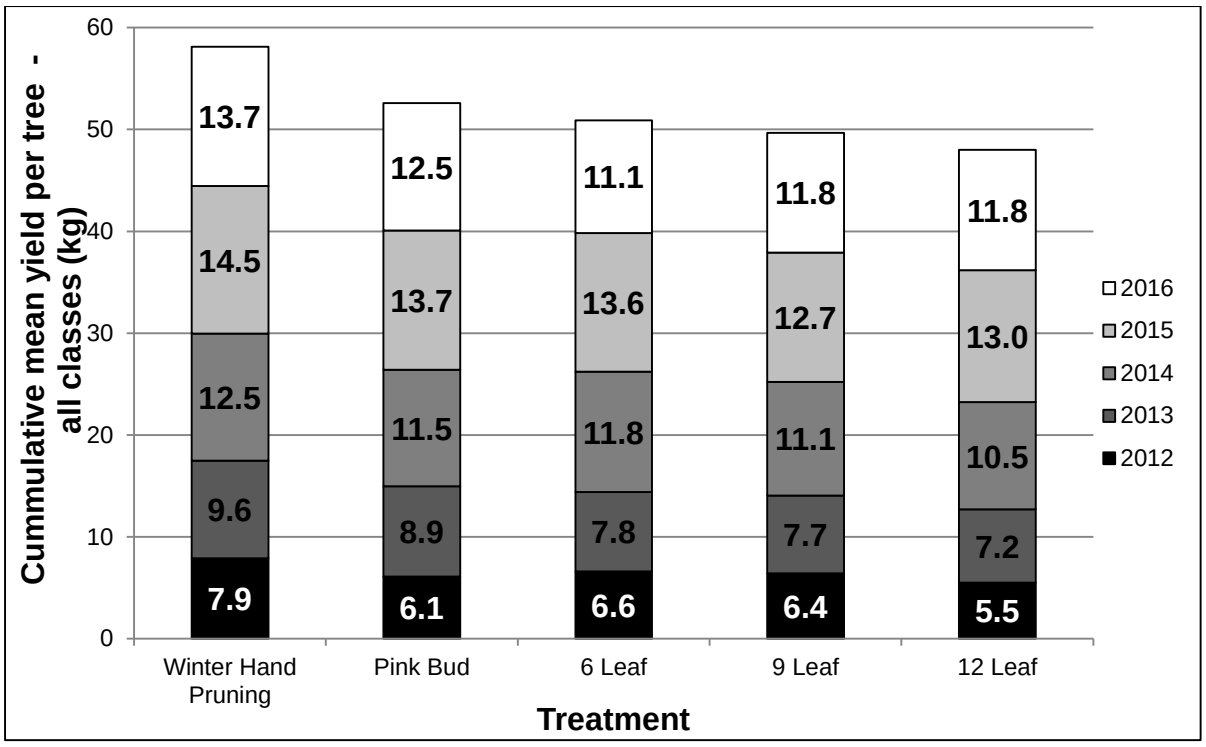


Figure 8. The effect of pruning treatments on cumulative mean yield per tree – all classes (kg) over 5 years. Sub treatment data is averaged for 2013 to 2016 as inter pruning was not initiated in 2012.

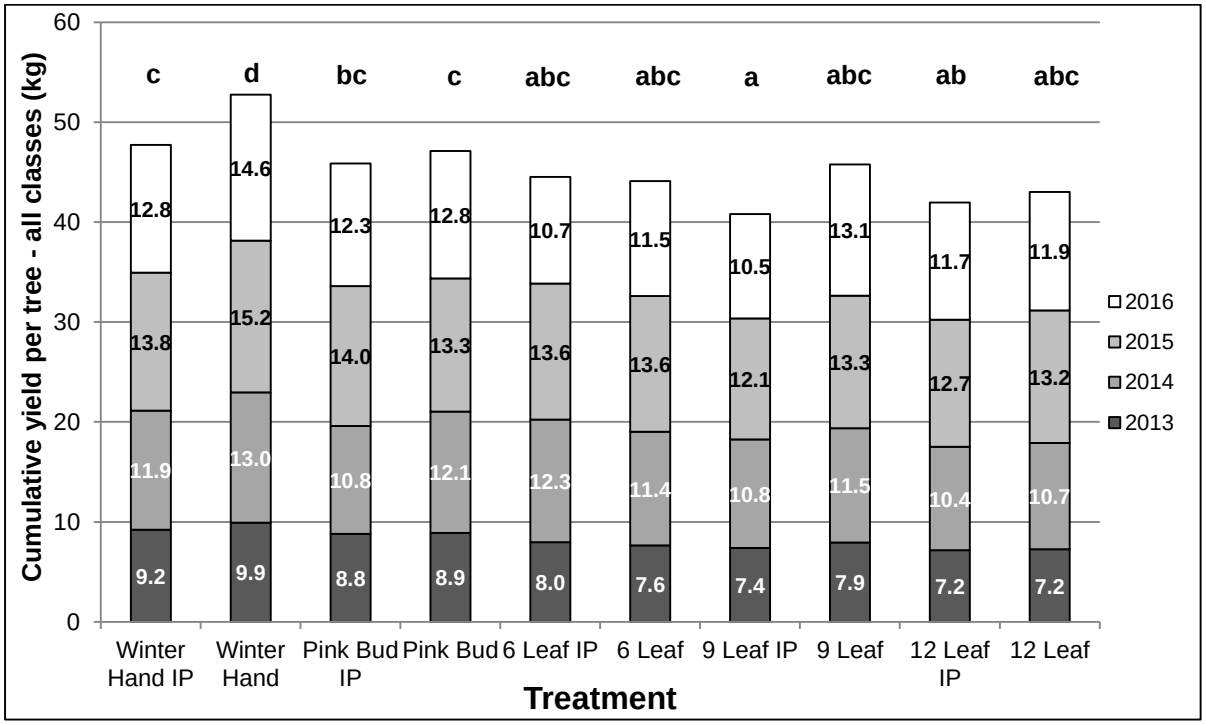


Figure 9. The effect of pruning treatments on cumulative yield per tree – all classes (kg) including sub treatments. Data for 2012 is omitted since inter pruning commenced in 2013. Statistical Multiple Range Test results sharing the same letter are not significantly different (P=0.0022).

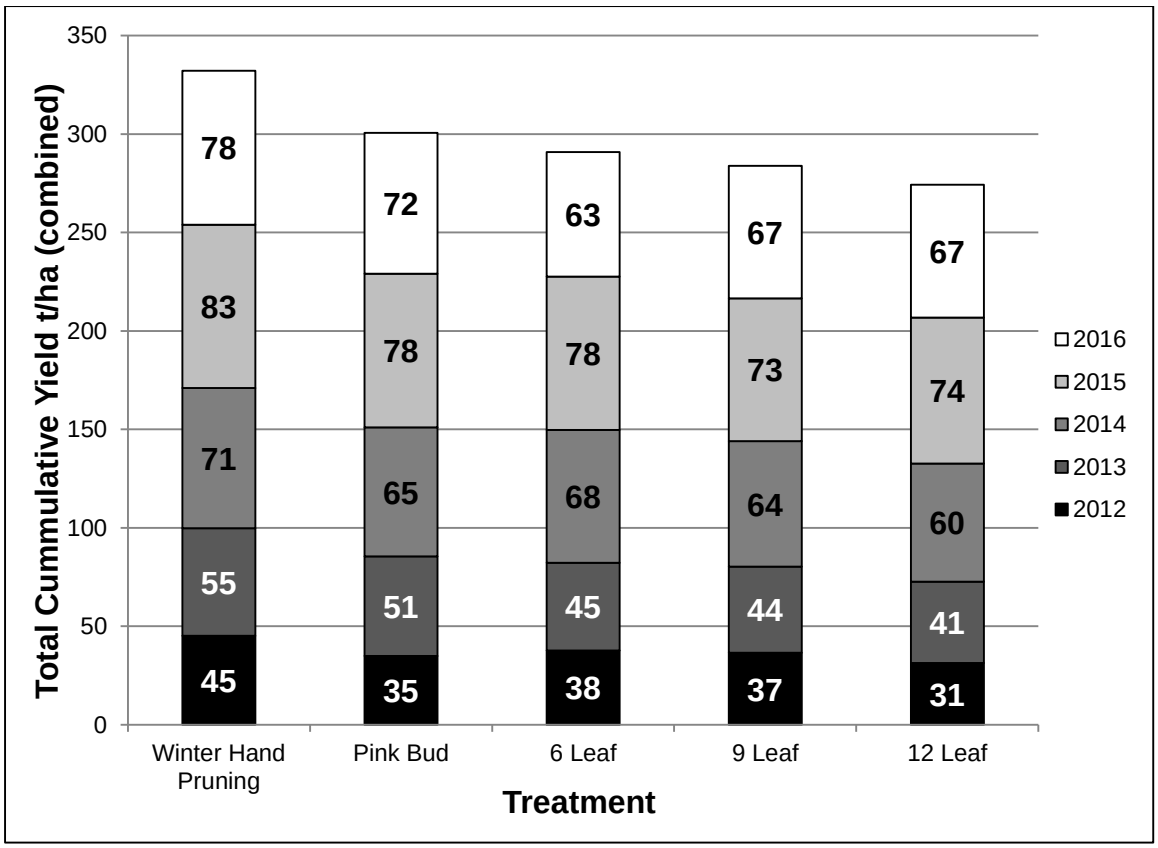


Figure 10. Total Cumulative Yield t/ha combined (excluding sub treatments) 2013 to 2016.

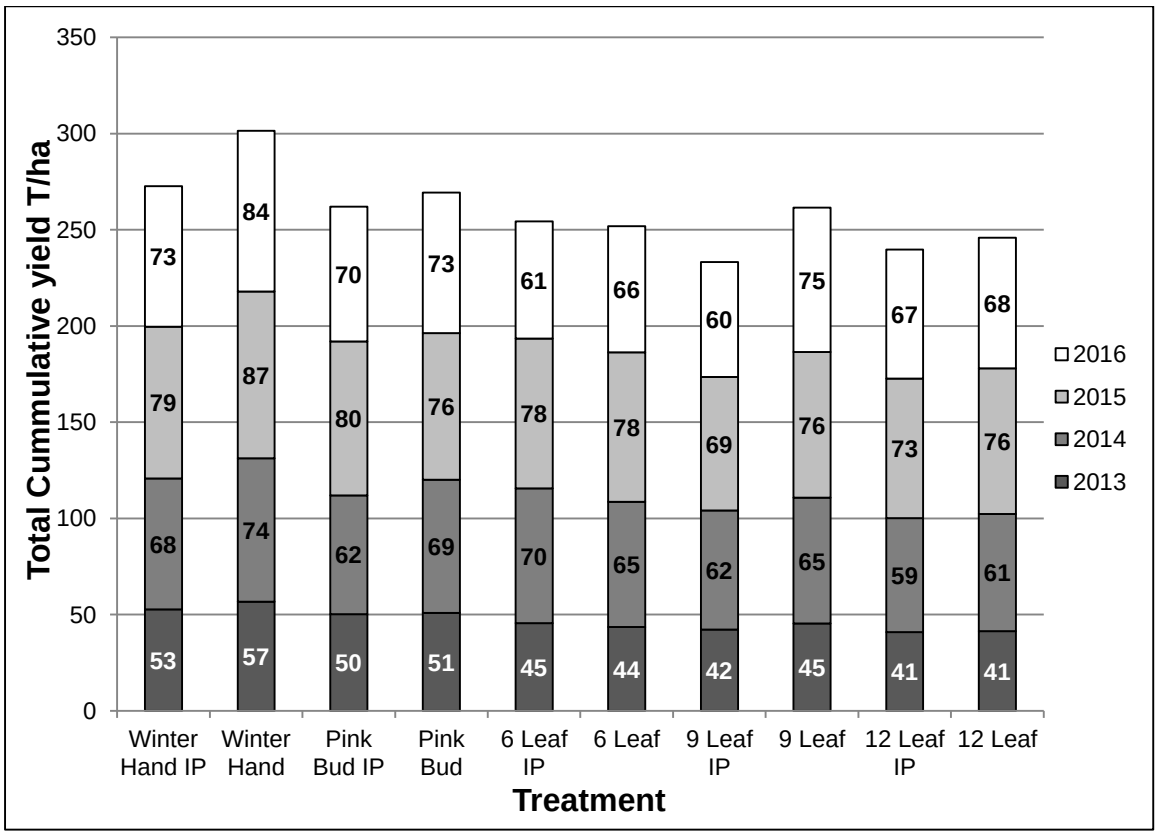


Figure 11. Total Cumulative Yield t/ha (including sub treatments) 2013 to 2016.

Fruit diameter and weight

Average fruit diameter varied between 61.68m (9 Leaf IP) and 58.99mm (12 Leaf IP).

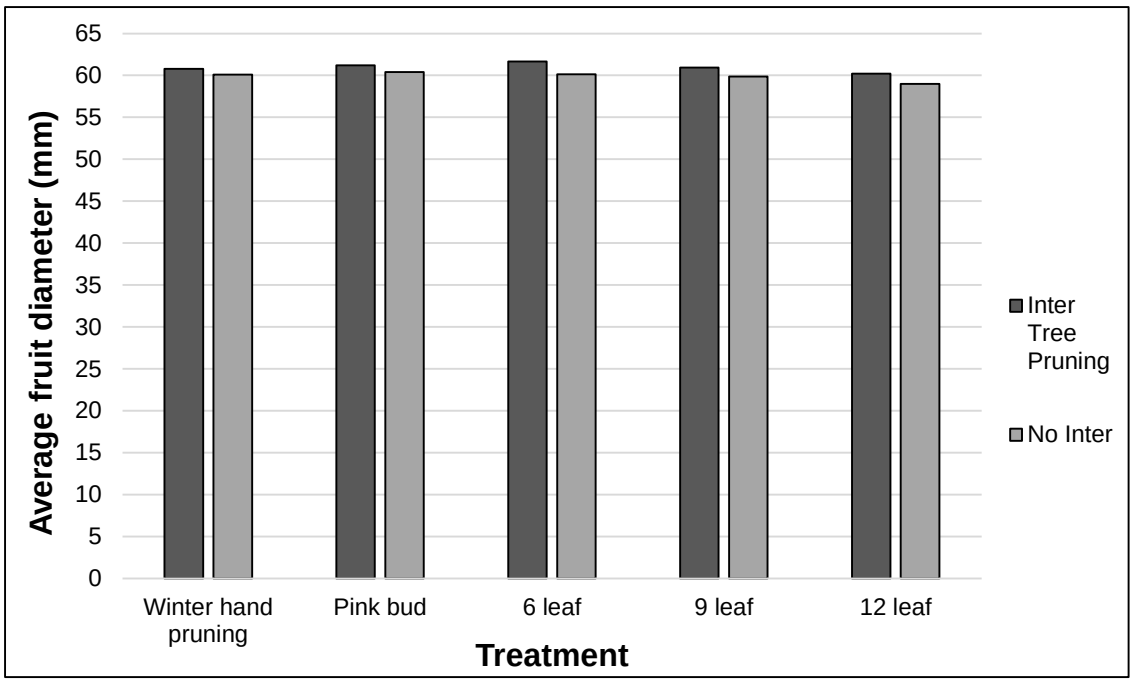


Figure 12. The effect of the pruning treatment on the average fruit diameter (mm) at harvest.

There were significant differences between treatments for average fruit weight (g). Lowest fruit weight was for 12 Leaf IP (93.73g) and highest was 6 Leaf IP (106.45g).

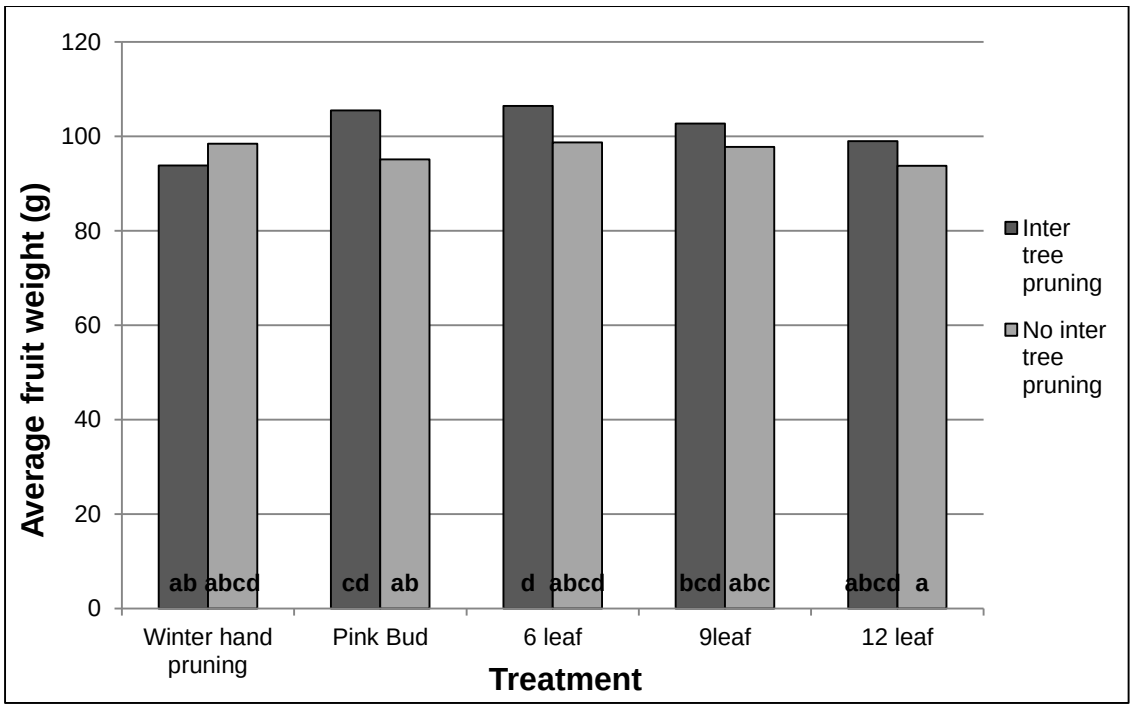


Figure 13. The effect of the pruning treatment on the average fruit weight (g) at harvest. Statistical Multiple Range Test results sharing the same letter are not significantly different (P=0.0432).

Fruit colour

There were statistically significant differences between the means for % Block Red of the sub sample assessed. 6 Leaf NIP (66%) was significantly higher than all other treatments except Winter Hand IP, 6 Leaf NIP, 9 Leaf NIP and 12 Leaf NIP. Pink Bud and 6 Leaf NIP had the lowest values (57% each).

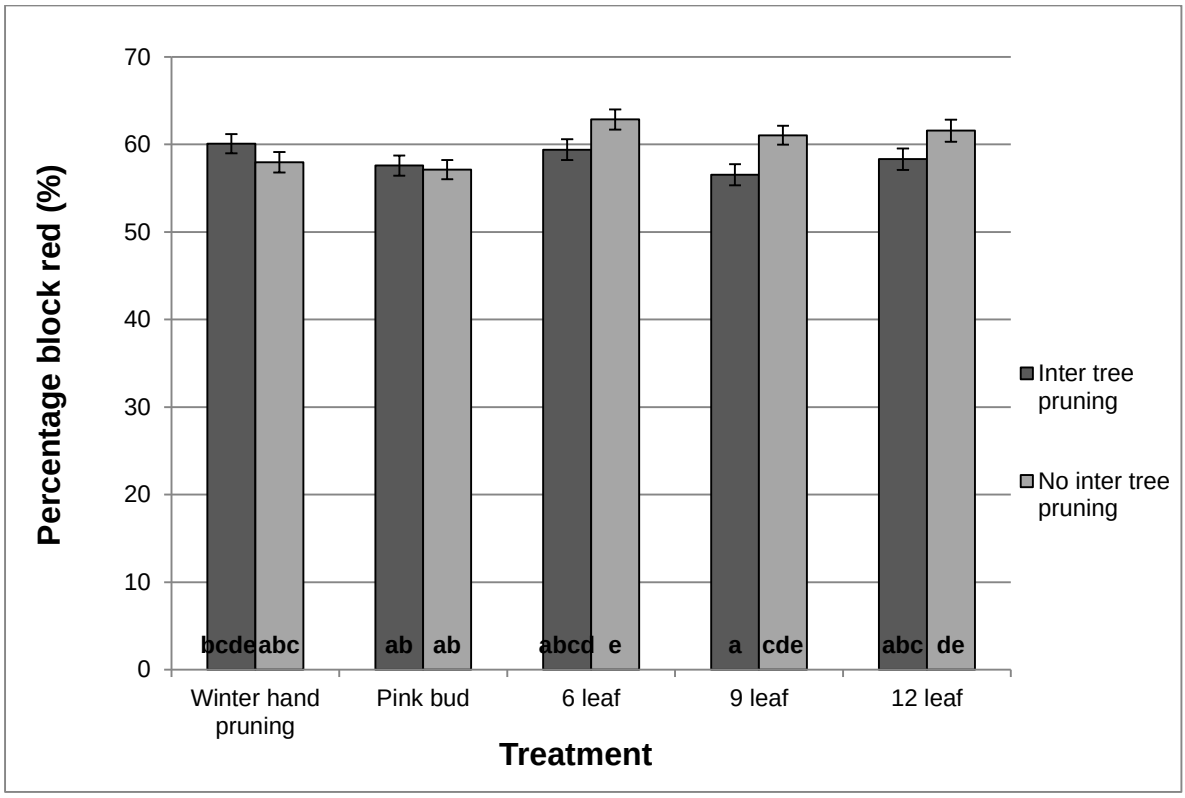


Figure 14. The effect of the pruning treatment on the percentage surface coloured block red at harvest. Statistical Multiple Range Test results sharing the same letter are not significantly different (P<0.0007).

Fruit quality and maturity

Winter Hand NIP had the most Class 1 fruit (90.77%) and 6 Leaf IP the least (82%). Winter Hand IP had the least Waste (2.11%) and 12 Leaf Non IP the most (6.58%). See Figure 15.

There were no significant differences between treatments and sub treatments for % starch (see Figure 16) (P=0.3263). At harvest, the percentage of the fruit surface stained black with iodine (the starch level) ranged between 96.8% (6 Leaf IP) and 90.5% (Pink Bud NIP).

There were significant differences between treatments and sub treatments for BRIXº (see Figure 17). BRIXº ranged between 10.16 (Winter Hand IP) and 9.27 (6 Leaf IP).

There were no significant differences between treatments for fruit firmness (see Figure 18) (P=0.0710). Fruit firmness ranged between 9.26 (Winter Hand NIP) and 8.73 (12 Leaf NIP).

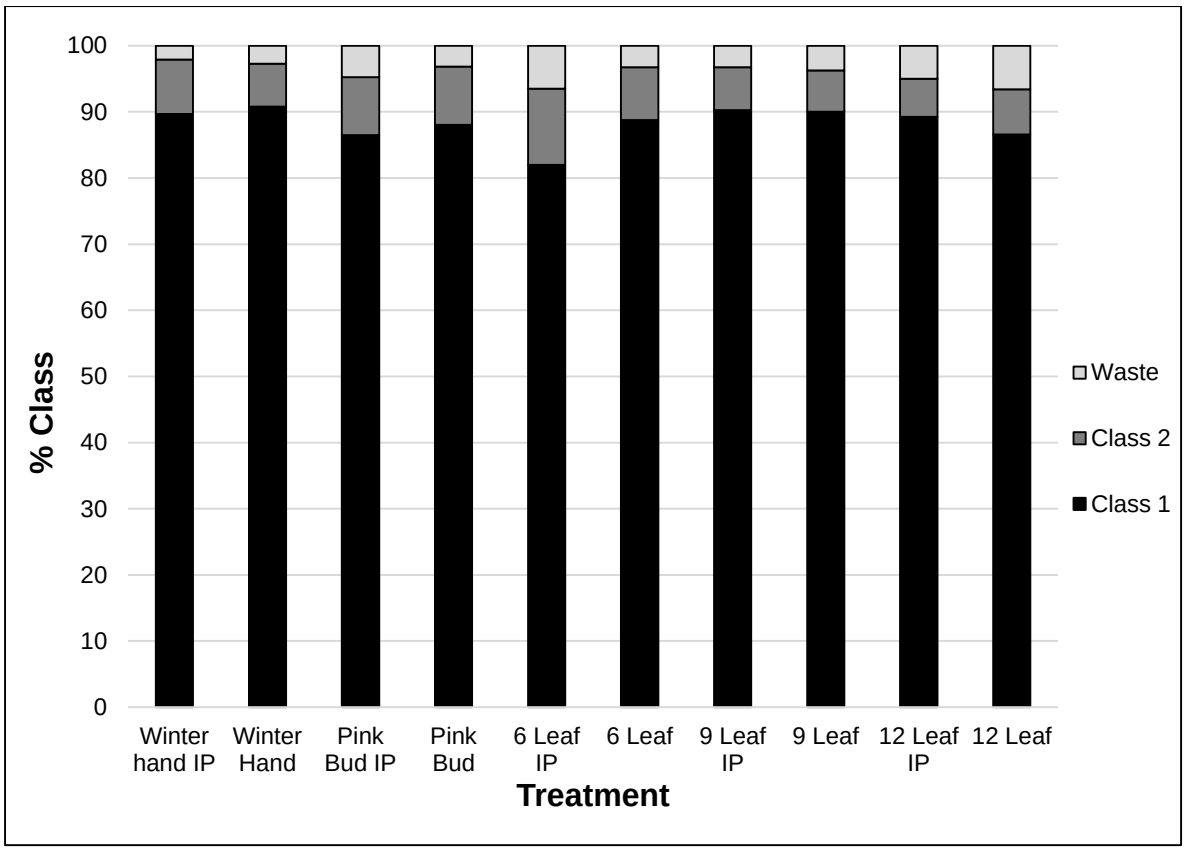


Figure 15. % Class

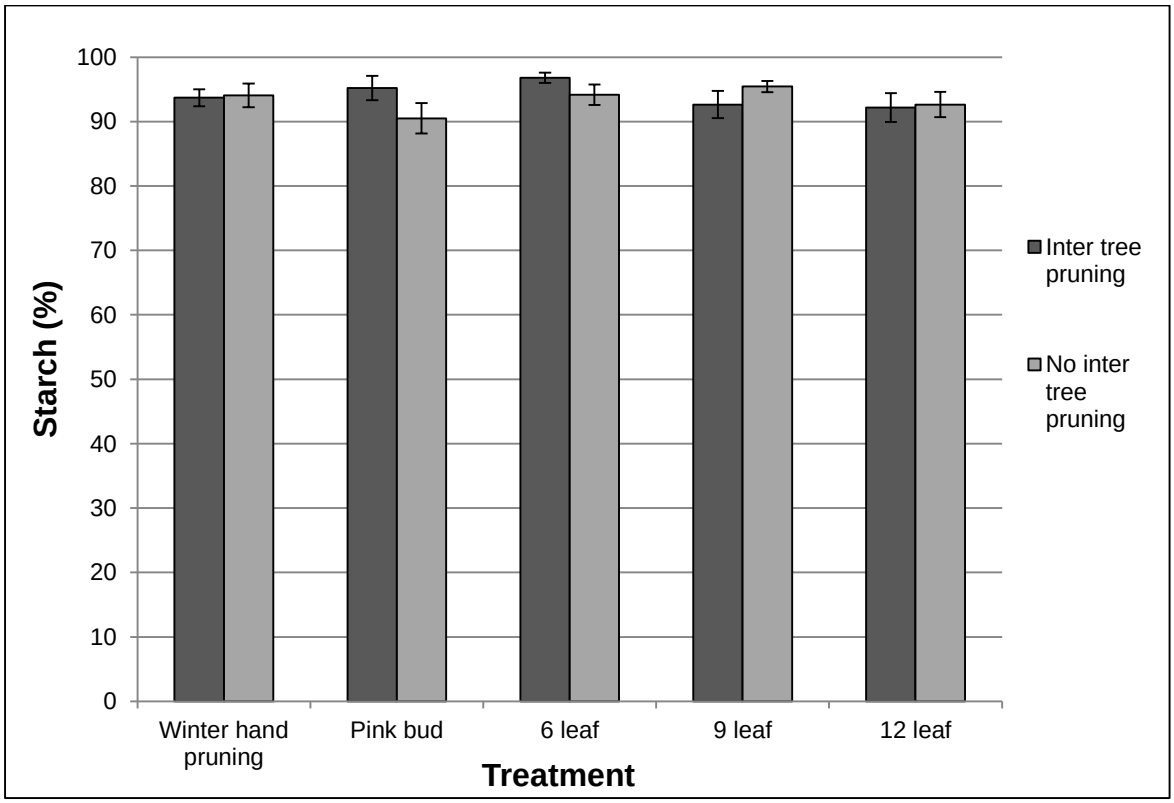


Figure 16. The effect of the pruning treatment on the average percentage starch (determined by standard iodine test) at harvest.

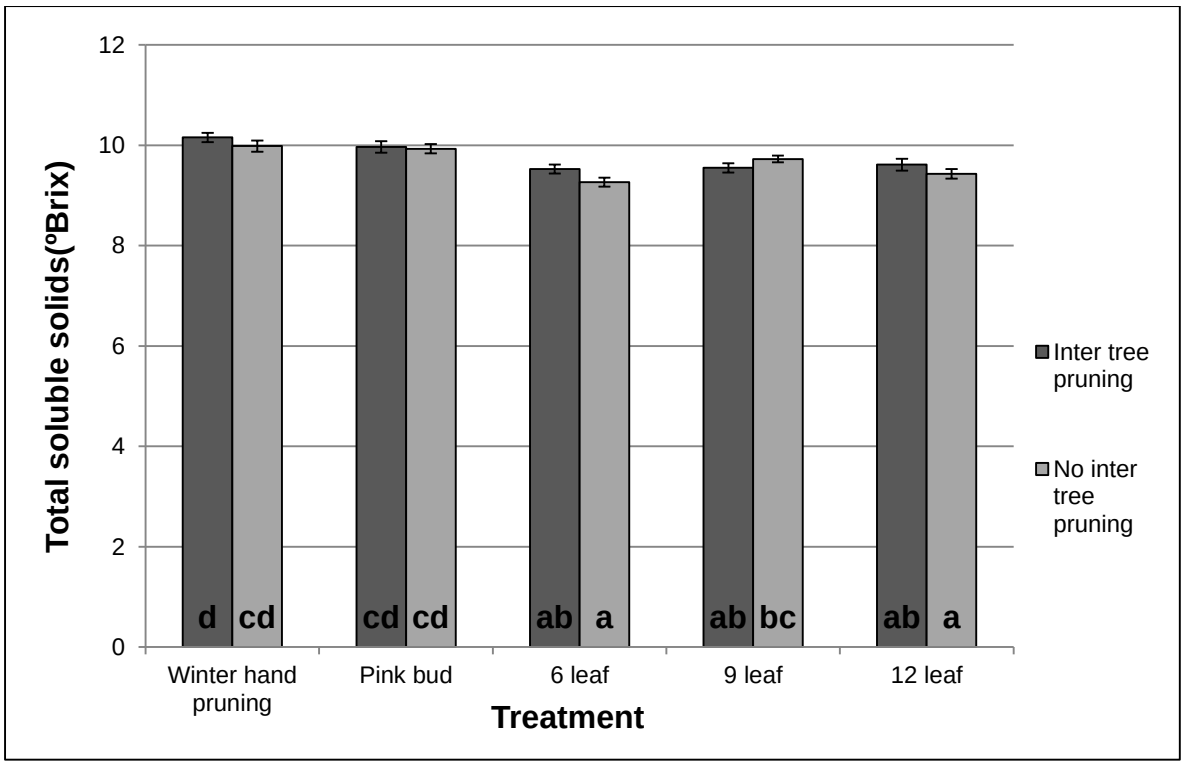


Figure 17. The effect of the pruning treatment on the average total soluble solids (Brix°) at harvest. Statistical Multiple Range Test results sharing the same letter are not significantly different (P<0.0000).

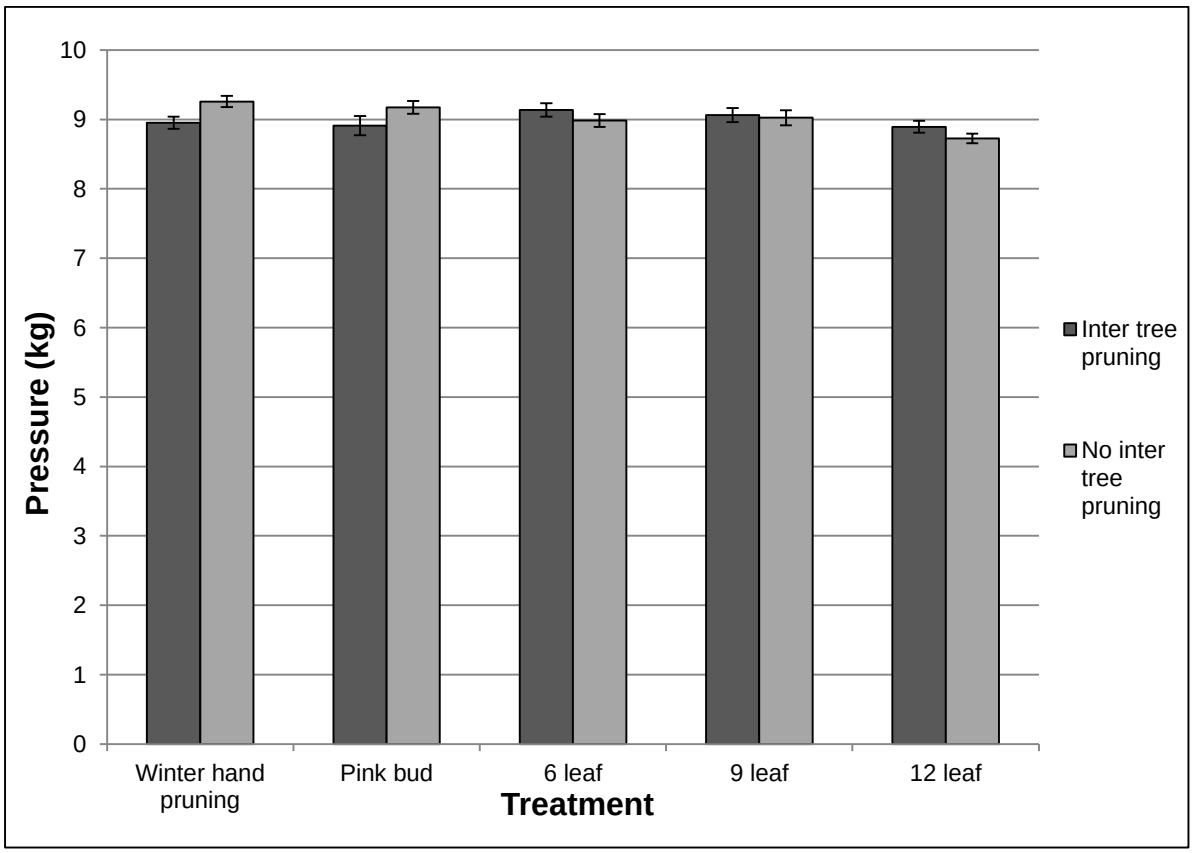


Figure 18. The effect of the pruning treatment on the average fruit firmness at harvest.

Leaf analysis

There were significant treatment effects recorded on Leaf Mineral Analysis for 3 macro elements (Phosphorous (P), Potassium (K) and Calcium (CA)) and 2 micro nutrients (Manganese (Mn) and Boron (B)). See Table 5.

Table 5. Leaf analysis results from sampling on 30 August 2016.

Leaf analysis	(% dry weight)					(mg/kg)				
	N	**P**	**K**	**Mg**	**Ca**	**Mn**	**B**	**Cu**	**Zn**	**Fe**
T1 Winter Hand Prune IP	2.26	0.18 ab	1.87 ab	0.15	1.31 cd	146.81 de	24.71 a	9.29	23.24	95.48
T2 Winter Hand NIP	2.22	0.19 abc	1.83 a	0.16	1.43 d	153.15 e	24.00 a	9.28	24.04	96.41
T3 Pink Bud IP	2.24	0.18 ab	1.95 abc	0.15	1.25 bcd	138.87 cde	25.05 a	8.82	21.84	88.92
T4 Pink Bud NIP	2.21	0.18 a	1.98 abcd	0.13	1.25 bcd	141.28 cde	24.86 a	8.64	22.17	94.64
T5 6 Leaf IP	2.09	0.20 d	2.23 e	0.14	1.00 abc	114.92 bcd	25.69 ab	8.84	21.47	87.38
T6 6 Leaf NIP	2.13	0.20 cd	2.12 cde	0.12	0.85 a	113.81 abc	25.32 a	8.93	19.31	97.40
T7 9 Leaf IP	2.13	0.20 d	2.14 de	0.13	0.94 abc	103.55 ab	27.46 b	8.96	18.37	91.62
T8 9 Leaf NIP	2.10	0.19 bcd	2.12 cde	0.14	0.98 abc	105.54 ab	25.95 ab	8.71	18.80	92.89
T9 12 Leaf IP	2.06	0.19 bcd	2.03 bcd	0.14	1.03 abc	106.29 ab	25.74 ab	9.09	18.45	96.10
T10 12 Leaf NIP	1.97	0.20 d	2.10 cde	0.13	0.89 ab	81.99 a	27.72 b	8.48	15.71	93.36
Significance (P value)	***n.s***	***0.0024***	***0.0009***	***n.s***	***0.0335***	***0.0010***	***0.0196***	***n.s***	***n.s***	***n.s***

See Appendix 2 Table 4 for Leaf Mineral Analysis normal parameters.

Fruit Dry Matter

There were statistically significant differences between treatments for % dry matter. Percentages ranged between 13.5% (Pink Bud IP) and 12.48% (12 Leaf NIP).

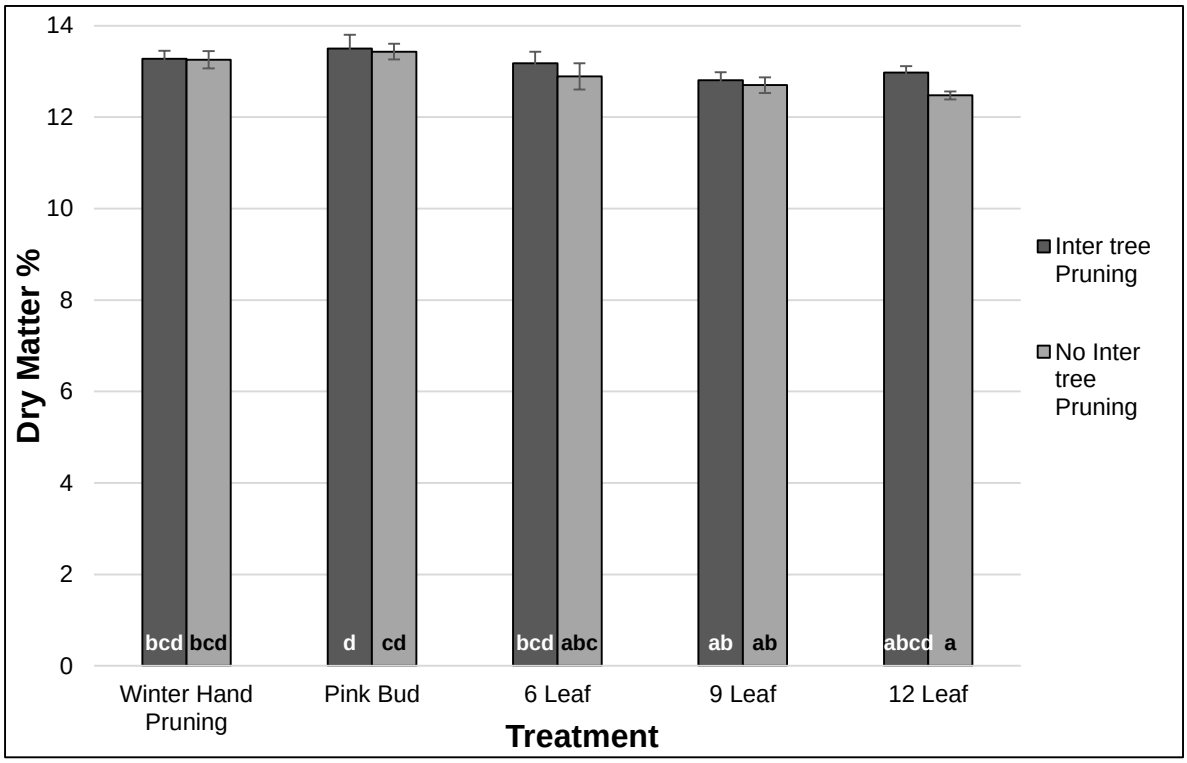


Figure 19. Fruit % dry matter from samples taken on 13 September 2016. Statistical Multiple Range Test results sharing the same letter are not significantly different (P=0.0212).

Discussion 2016

As in previous years, delaying mechanical cuts through the 2016 season resulted in significant reductions in regrowth at each event, with the 12 Leaf stage resulting in the least regrowth. Again, the IP plots tended to have slightly more growth compared to NIP. There was very little regrowth between measurements in August and October 2016.

Yields in 2016 were lower than 2015. Although cropping profiles were similar to 2014 and 2015, unlike previous years there were statistically significant differences in average yield per tree (all classes) in 2016. There were also significant differences between sub treatments for Winter Hand (NIP produced 1.9kg more per tree than IP) and 9 Leaf (NIP produced 2.7kg more per tree than IP). Winter Hand NIP and 9 Leaf IP were again the highest and lowest yielding treatments. Cumulative yields per tree (all classes) and t/ha remain highest in the Winter Hand plots for both combined and sub treatments. As in 2014 and 2015, IP reduced yields because of decreased amounts of fruiting wood compared to NIP.

Fruit diameter was smaller in general in 2016 but higher average fruit diameter was maintained for IP plots compared to NIP plots likely because of a more open tree structure. However, differences were less than 3mm between the largest and smallest average fruit diameter. All were above the acceptable minimum of 55mm but below the 63-68mm optimum supermarket standard (Quality Fruit Group 2016).

Where inter tree pruning was carried out there was a benefit in terms of improved fruit weight but in general fruit weight was more variable and lighter on average in 2016 compared to 2015. 12 Leaf NIP fruits were significantly lighter than Pink Bud IP and 6 Leaf IP.

The *Galaxy* clone of Gala used in this project is naturally a well coloured clone but fruit colour in 2016 was generally poor. Only four out of ten treatments (Winter Hand IP, 6 Leaf NIP, 9 Leaf NIP and 12 Leaf NIP) reached bold red colour over 60% of the skin. Low night time temperatures are known to increase production of anthocyanins and red colouration (Ritenour and Khemira 2007) so the high night time temperatures around harvest time (FAST & Met Office 2017) would have been a contributory factor to low colour in 2016.

All treatments had over 85% Class 1 fruit in 2016 except 6 Leaf IP. The treatments with the highest Class 1 % (Winter NIP and 9 Leaf NIP) also had the highest yields per tree.

Starch levels from samples taken at harvest were high at over 90% for all treatments and there were no significant differences. To enable commercial operation to continue as usual fruit samples from the trial plots for quality assessments were picked at the commencement of the grower's harvest. Starch levels of >85% are necessary for long term storage ie to March/April (Quality Fruit Group 2016) so the early sampling and harvest date was acceptable when assessing starch.

BRIX° levels for all treatments in 2016 were below commercially acceptable standards (>12 (Quality Fruit Group 2016)). This could have been due to being harvested earlier than the rest of the orchard not used in the trial and the climatic conditions around harvest (including low rainfall (Southern Water 2016) and high day and night temperatures (FAST & Met Office 2017)) but sugar levels would have improved in store (Quality Fruit Group 2016). There was also a significant reduction of fruit sugar levels in the later summer cuts (as seen in the early years of the trial but not in 2015).

Fruit firmness values between treatments were very similar (average of 9kg over all treatments) and all were above the minimum standard (9.1) for long term storage at appropriate starch (Quality Fruit Group 2016).

The trend for Winter Hand and earlier mechanically pruned plots having higher leaf Nitrogen levels than the later cuts as seen in 2014 and 2015 continued but there were no significant

differences between treatments for Nitrogen. Generally, later pruned plots had lower P, K, Ca and Mn but higher B in the leaves. Low K may lead to lower BRIX (Nava et al 2008).

Fruit dry matter percentage for all treatments was commercially acceptable (Quality Fruit Group 2016).

Conclusions 2016

The significant differences in growth response to the cuts at the different stages through the season are consistent through the years and must be taken into account by growers contemplating mechanical pruning. Where tree control is the major consideration delayed pruning is advised.

The early sampling and harvest date (an 8 to 9 day advancement compared to commercial operations) may have had small effects on the results of other assessments including fruit size and yield.

The orchard is irrigated but the below average rain fall from July to October (Southern Water 2016) combined with the higher than average temperatures in August and September and high night time temperatures (FAST & Met Office 2017) leading up to harvest may have contributed to the smaller fruit size and poor colour.

Adequate irrigation and consideration of colour improving products in high risk years should be considered.

Amelioration (foliar or fertigation) for low P, K, Ca and Mn may be required if choosing to prune after Pink Bud or to ensure adequate BRIX^{o} where orchards have a problem.

As with all pruning interventions it is critically important that growers and their staff assess trees and orchards each year and understand the implications of the degree and the timing of pruning management, in terms of effects on yield, growth and fruit bud development.

Results Summary and Discussion 2012 - 2016

There were consistent effects of pruning timing on one assessment parameter only namely yield (per tree, t/ha, cumulative and Class 1) which was higher for Winter Hand and lowest for 9 Leaf IP and 12 Leaf IP.

There were repeated positive effects for very few parameters but including starch for 6 Leaf IP and colour for 9 Leaf NIP which had increased levels in 3 out of 5 years.

There were repeated negative effects for very few parameters but including BRIX for 6 Leaf which had reduced levels for 3 out of 5 years.

Pruning Timing

Dates of the mechanical pruning were variable in each year of the trial. See Table 6.

The 2013 season was one of the latest in the last 20 years and the Pink Bud cut was carried out 15 days later than the earliest pruning date for that stage in the trial. The delay in blossom and growth stages in 2013 was reflected in the later Fruit Wall cuts compared to any other year.

2013 also had the longest period between Pink Bud and 12 Leaf cuts whereas 2015 had the shortest.

In 2014 and 2015 Pink Bud was reached considerably earlier than other years.

Table 6. Date of mechanical pruning for each treatment 2012-2016.

Treatment / days / year	**2102**	**2013**	**2014**	**2015**	**2016**
Hand / Inter Pruning		22-Jan	07-Mar	22-Jan	11-Mar
Pink Bud	03-May	08-May	23-Apr	28-Apr	06-May
Days between Pink Bud & 6 Leaf	26	44	21	34	35
6 Leaf	29-May	21-Jun	14-May	01-Jun	10-Jun
Days between 6 & 9 Leaf	17	11	20	10	14
9 Leaf	15-Jun	02-Jul	03-Jun	11-Jun	24-Jun
Days between 9 & 12 Leaf	18	13	22	19	6
12 Leaf	03-Jul	15-Jul	25-Jun	30-Jun	30-Jun
Total days between Pink Bud & 12 Leaf	61	68	63	63	55

Hand pruning – hours per hectare

The average time taken to prune the Winter Hand treatments in this trial was used to calculate hours per hectare and based on recorded seconds per plot (same operative each year) (see Table 7). NB figures used in the Financial Benefits section where taken from commercial practice since it was felt this was a more accurate representation for growers.

Table 7. Hours to prune per hectare per year.

Treatment / year	**2012**	**2013**	**2014**	**2015**	**2016**
Winter Hand IP	N/A	28	19	20	20
Winter Hand NIP	N/A	21	25	21	23

Vegetative regrowth

There were significant effects on shoot length at both events in every year of the trial. In every year later pruned treatments had significantly reduced regrowth. In 2015 and 2016 shoots were significantly shorter for NIP compared to IP within treatment timings - a trend started in 2014.

In 2012 growth ceased and formed a terminal bud on a high percentage of shoots before 12 leaves had been produced. The cut was made when 50% of the shoots formed a terminal bud. In 2013 shoots were observed to produce shoots with more than 12 leaves despite the late season.

Yield – per tree

Highest and lowest yielding treatments were the same in 2015 and 2016.

There were significant differences for average yield per tree in 2012, 2013 and 2016 but not in 2014 or 2015.

Differences between IP and NIP sub treatments have become more apparent in later years, in particular in 2016 where NIP had higher yields.

Whilst Winter Hand NIP has maintained the highest yields per tree throughout the trial, in 2016 Pink Bud IP, Pink Bud NIP and 9 Leaf NIP had statistically similar yields to Winter Hand IP.

Combined (i.e. sub treatments averaged to take account of the fact that IP was not introduced until 2013) and cumulatively, Winter Hand produced an average of 58.1kg per tree over 5 years and the other treatments 52.6kg, 50.9kg, 49.7kg and 48.0kg respectively (Pink Bud, 6, 9 and 12 Leaf).

On examining the average cumulative yield per tree for all sub treatments between 2013 and 2016 Winter Hand NIP had the most kg per tree. Winter Hand IP and Pink Bud NIP yields were similar and the next best yielding treatments were Pink Bud IP and 9 Leaf NIP. See Table 8.

Table 8. Average cumulative yield per tree including all sub treatments (2013 and 2016).

Treatment	kg per tree
Winter Hand IP	47.7
Winter Hand	52.8
Pink Bud IP	45.9
Pink Bud	47.1
6 Leaf IP	44.5
6 Leaf	44.1
9 Leaf IP	40.8
9 Leaf	45.8
12 Leaf IP	42.0
12 Leaf	43.0

Yield – t/ha

Combined (i.e. not including inter pruned sub treatments) cumulative yields t/ha showed that Winter Hand produced an average of 332 t/ha over 5 years and the other treatments 301, 291, 284 and 274 respectively (Pink Bud, 6, 9 and 12 Leaf).

On examining the average cumulative yield t/ha including all sub treatments (2013 to 2016) Winter Hand NIP had the highest t/ha. Winter Hand IP and Pink Bud NIP were the next highest yielding treatments and Pink Bud IP and 9 Leaf NIP had similar yields. See Table 9.

Table 9. Average cumulative yield t/ha including all sub treatments (2013 to 2016).

Treatment	t/ha
Winter Hand IP	273
Winter Hand	301
Pink Bud IP	262
Pink Bud	269
6 Leaf IP	254
6 Leaf	252
9 Leaf IP	233
9 Leaf	261
12 Leaf IP	240
12 Leaf	246

Cumulative Class 1 yields for the trial period 2013 to 2016 were calculated using t/ha and % Class data. Results showed that both Winter Hand treatments yielded more Class 1 than any other, followed by Pink Bud IP and NIP and 9 Leaf NIP. Winter Hand NIP, 9 Leaf NIP and 12 Leaf IP were the only treatments to increase in yields from 2015, see Figure 20.

Percentage pollinators and diseased trees were calculated for the period 2013 to 2016 and Class 1 yields adjusted. Pollinators comprised 8% of the orchard from trial commencement and in 2016 there were approximately 5% missing trees due to canker. A sliding scale was used to adjust downwards the proportion of diseased trees in earlier years, see Figure 21.

Adjusted Class 1 yields t/ha illustrate a fair representation of actual yields and show that again Winter Hand treatments were higher than any of the Fruit Wall treatments with Pink Bud IP and NIP and 9 Leaf NIP the closest rivals.

The trees in the fruit wall were in their 7th leaf and 6th fruiting year. Yield expectations would be in excess of 50 t/ha (FAST 2017).

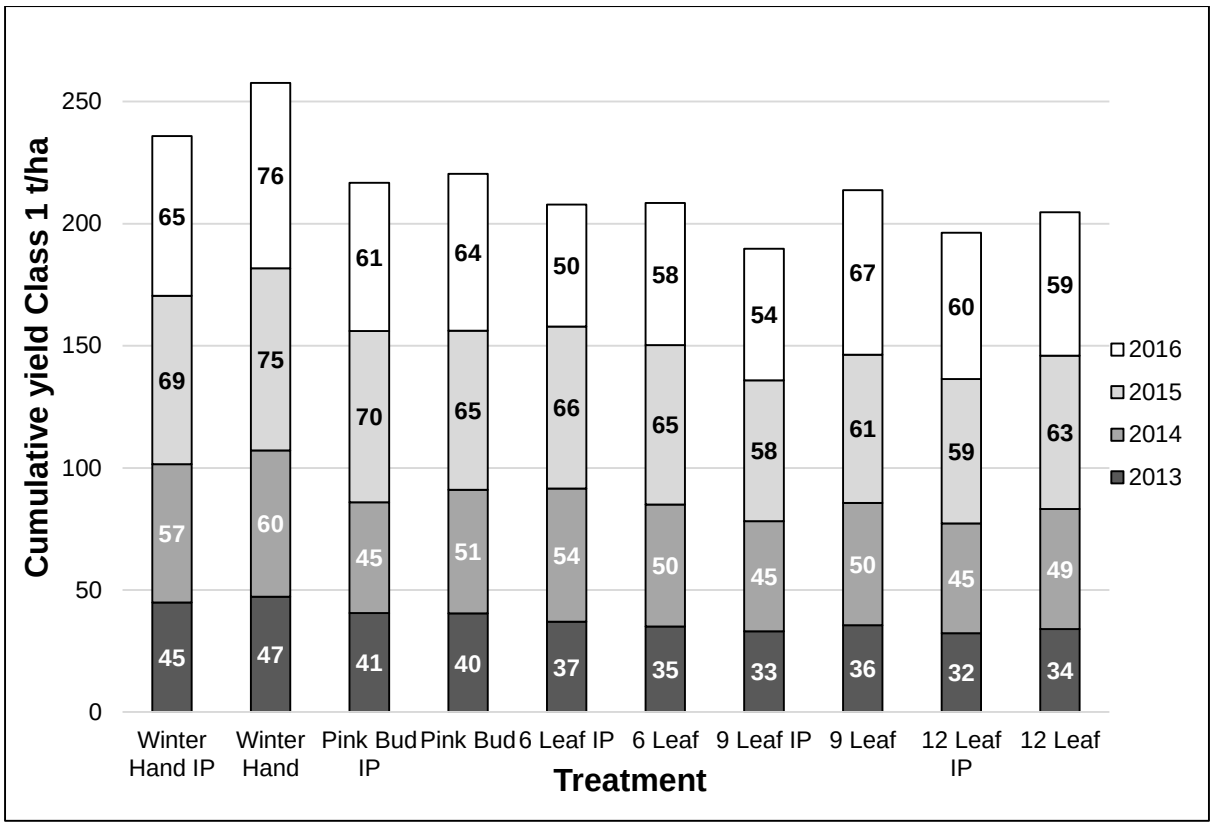


Figure 20. The effect of treatments on cumulative yield per treatment – Class 1 t/ha.

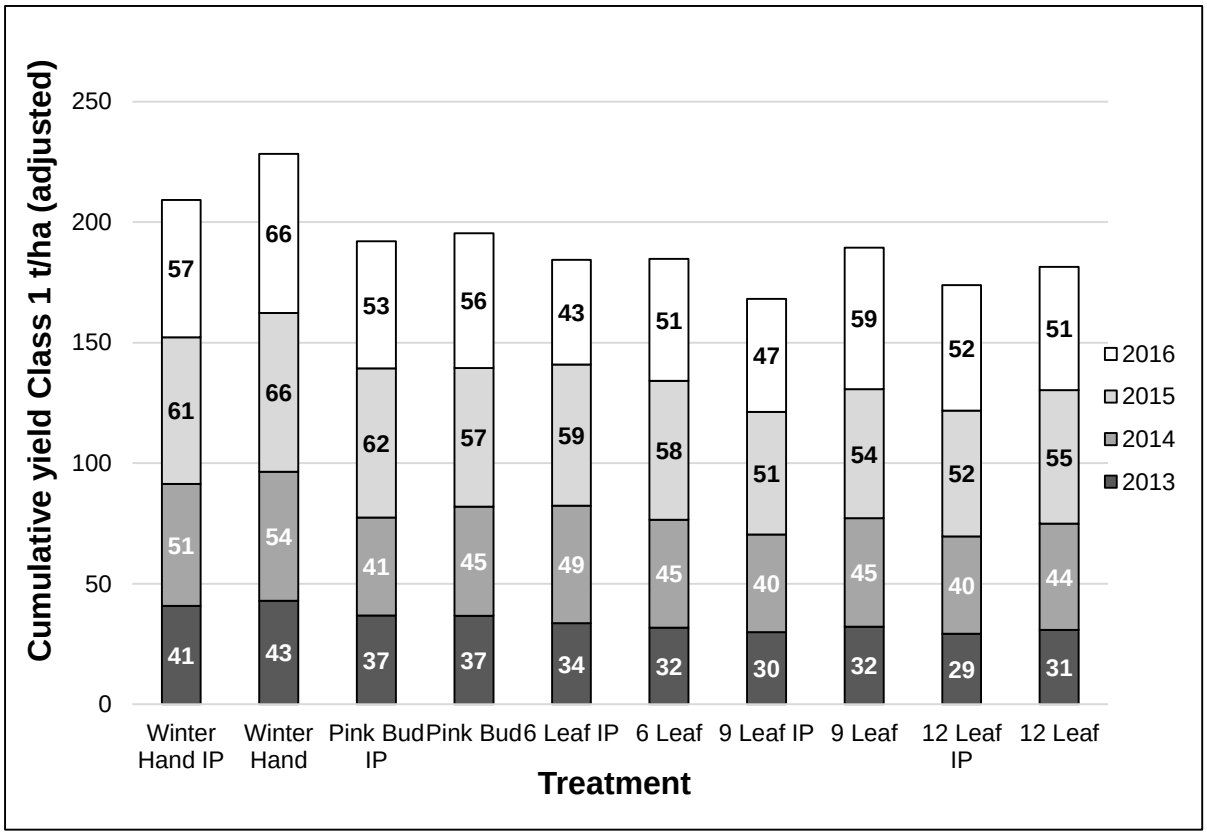


Figure 21. The effect of pruning treatments on cumulative yield per treatment – Class 1 t/ha adjusted for % pollinators and diseased trees within trial plot orchard.

In 2016, and based on adjusted Class 1 cumulative t/ha, only 9 Leaf NIP increased in yields compared to 2015. Winter NIP and 12 Leaf NIP maintained the same yields. All other treatments had decreased yields (adjusted) compared to 2015.

Trees used in the trial were selected as those most representative of the plots i.e. as similar to one another as possible to minimise variables. Therefore, the trees picked throughout the trial were likely to be of very good quality and any that were damaged, badly affected by canker or not true to type would have been rejected. The percentage was estimated to be as high as 12.5% (see Table 10).

Table 10. Cumulative yield Class 1 t/ha adjusted for pollinators and diseased trees plus % poor quality trees.

Treatment	2012-2016 Cumulative Class 1 t/ha adjusted	2012-2016 Cumulative Class 1 t/ha adjusted minus % poor quality trees
Winter Hand IP	245	214
Winter Hand	264	231
Pink Bud IP	219	191
Pink Bud	222	194
6 Leaf IP	213	187
6 Leaf	214	187
9 Leaf IP	196	171
9 Leaf	217	190
12 Leaf IP	198	173
12 Leaf	205	180

It should be noted that cumulative values have not been adjusted for headlands or hedgerows i.e. values relate to tree hectares.

Fruit diameter and weight

Fruit diameters in 2012, 2015 and 2016 were more similar between treatment and sub treatments than in 2013 when there was significant improvement in fruit size in the later pruned

plots. Over the years average fruit diameters were variable. Fruit diameters were lowest in 2012 and highest in 2015.

Table 11. Fruit size mm summary.

Treatment / Year	2012	2013	2014	2015	2016
1	58.8	62.8	61.5	65.0	60.8
2	58.8	60.9	61.2	65.2	60.1
3	59.6	62.9	64.8	65.4	61.2
4	59.6	61.7	61.2	65.5	60.4
5	59.7	63.3	64.2	66.0	61.7
6	59.7	63.6	63.3	65.3	60.1
7	59.1	62.9	61.5	66.1	60.9
8	59.1	63.0	61.9	65.3	59.9
9	58.9	64.7	61.4	66.2	60.2
10	58.9	64.2	60.9	64.9	59.0

Fruit weights were less variable in 2012 and 2015. There were significant effects in 2013, 2014 and 2016. In 2013 and 2014 there were advantages for later pruned and inter pruned treatments. In 2014 Pink Bud IP was significantly heavier than any other treatment apart from 6 Leaf IP. The pruning cuts at 9, 6 and 12 Leaf IP appeared to have a benefit in terms of improved fruit weight in 2015. In 2016 some IP sub treatments had significantly heavier fruit compared to NIP.

Fruit colour

There were no statistical differences between treatment for % block red in 2012, 2013 or 2014.

Statistical differences between treatments in 2015 showed that there were advantages / disadvantages for % block red for IP or NIP depending on the timing of the mechanical pruning. For example, Winter Hand and 6 Leaf NIP had significantly better colour than Winter Hand and 6 Leaf IP but 9 Leaf NIP had significantly better colour than 9 Leaf IP.

In 2016 6, 9 and 12 Leaf NIP sub treatments all had significantly better colour than IP.

All pruning treatments had sufficient colour to meet Class 1 standards in every year except for 2016 (of the sub sample assessed).

Fruit quality and maturity – % Class

Class was not assessed in 2012 and not reported in 2013 and 2014.

Percentage Class 1 of 80% and over was reported for every treatment in 2015 and 2016. See Table 12.

Class 1 percentages were lower in 2013 and 2014. Highest Class 1 was recorded for Winter Hand IP in both years (underlined in Table 12). 9 Leaf IP and NIP had the lowest Class 1 % in 2013 (italics in Table 11). In 2014 Pink Bud IP and 9 Leaf NIP had the lowest Class 1 %.

Pink Bud IP had the highest percentage Class 1 in 2015 and 9 Leaf NIP the lowest.

Winter Hand NIP had the highest percentage Class 1 in 2016 and Pink Bud IP and 12 Leaf NIP the lowest.

Class 1 percentages were lowest in 2014 but generally increased over the duration of the trial and in 2015 and 2016 were above commercially acceptable grade out standards of 80-85% (FAST 2016).

In 2016 both 9 Leaf IP and NIP had the same Class 1 % as Winter Hand IP.

Table 12. % Class 1.

Treatment/year	**2013**	**2014**	**2015**	**2016**
Winter Hand IP	**85%**	**83%**	87%	90%
Winter Hand	83%	80%	86%	**91%**
Pink Bud IP	81%	74%	**88%**	***87%***
Pink Bud	79%	***73%***	86%	88%
6 Leaf IP	81%	78%	85%	82%
6 Leaf	80%	77%	84%	89%
9 Leaf IP	***78%***	***73%***	83%	90%
9 Leaf	***78%***	77%	***80%***	90%
12 Leaf IP	79%	76%	81%	89%
12 Leaf	82%	81%	83%	***87%***

Fruit quality and maturity – % starch

There were no statistically significant differences between treatments for % starch in any year of the trial indicating that the treatments are not affecting the development of fruit maturity (and therefore not advancing or delaying harvest).

There was more variability in results in 2014 and 2015 when the range between maximum and minimum was 11%. Starch levels were lowest at harvest in 2012 and 2015 when levels were 80% or under for most treatments. The range in 2012 was 9%. Starch levels at harvest were higher in 2014 and 2016 (over 90%) but the range in 2016 was only 6%. The lowest range of starch was 5% in 2013. In every year the trial harvest date was governed by the grower's maturity tests and picking schedule and the % starch determined from samples at harvest.

Fruit quality and maturity – BRIX^{o}

Fruit sugar content was below BRIX^{o} 12 for all treatments in every year apart from 2012. This is below commercially acceptable standards (Quality Fruit Group 2016).

There were significant effects on BRIX^{0} in every year of the trial except 2015 but results were not consistent.

In 2012 12 Leaf pruning timing had significantly lower fruit sugar content than any other treatment. Pink Bud had the highest of 12.5 which was statistically similar to Winter Hand and 6 Leaf.

In 2013 treatments receiving later mechanical pruning generally had lower BRIX^{0} levels than Winter Hand and Pink Bud except 12 Leaf IP which had the highest fruit sugar content of 11.2. 6 Leaf IP had the lowest.

In 2014 Pink Bud IP had significantly higher BRIX^{0} (11) than any other treatment all of which were statistically similar.

BRIX^{0} levels in 2015 were very similar averaging 10.5 and the significant reduction of fruit sugar levels seen in later summer cuts was not repeated.

In 2016 later mechanically pruned cuts generally had significantly lower fruit sugar levels. Highest fruit sugar was recorded for Winter Hand IP (10.2). 6 Leaf NIP had the lowest BRIX^{0} of 9.3.

Fruit quality and maturity – fruit firmness

There were no significant effects on fruit pressure in any year of the trial except 2012 when Pink Bud had statistically higher pressure (10.7kg) than any other treatment. 9 Leaf had the lowest fruit firmness of 10.2kg but which was statistically similar to 6 and 12 Leaf.

Fruit firmness was lower in 2014 and 2015 (between 7kg and 8kg) and higher in 2013 and 2016 (between 8kg and 9kg).

There was no consistent differences in fruit firmness between IP and NIP sub treatments in any year.

Fruit firmness of 9kg is an acceptable minimum commercial standard at harvest for storage beyond March of the following year (Quality Fruit Group 2016).

Fruit analysis

Fruit was sampled and assessed for mineral content in 2012, 2013 and 2014.

No significant effects were noted in fruit mineral analysis in any year except for 2014 when significantly higher P levels were noted in Pink Bud IP (10.2). Winter Hand NIP had the lowest P levels of 8.74. These levels were adequate for storage purposes until April (FAST 2017).

Leaf analysis

There were significant differences in some nutritional elements for leaves in every year of the trial except for 2015.

In 2012, Copper levels were significantly higher in 12 Leaf compared to 6 and 9 Leaf but these results were not repeated in any subsequent year.

In 2013, there were significant treatment differences in Nitrogen, Magnesium and Calcium. Leaf N and Mg were lower than optimum (see Appendix 2) in the plots pruned at 6 and 9 Leaf. Winter Hand and Pink Bud had the highest N levels. Winter Hand and 12 Leaf had the highest Mg levels. Calcium levels were variable with significantly lower levels observed in 6 Leaf and higher levels observed in 12 Leaf IP and NIP and Winter Hand NIP. Whilst there were significant differences in Manganese and Boron levels all treatments were within industry standard range (see Appendix 2). The fact that the trees pruned later were still vegetatively active may account for some of these effects i.e. the reduction in N and Mg levels.

In 2014 12 Leaf had significantly lower N levels than other treatments and generally Winter Hand Pruned and earlier cuts had higher N levels. Statistical differences between the treatments for Potassium and Calcium plus Copper and Zinc were recorded but with no single treatment significantly higher or lower than the others. Copper levels were high in 2014 but not excessive.

Generally, NIP treatments had higher K but there did not appear to be any trends for the other elements showing significant differences.

In 2015 and 2016 the trend for Winter Hand and earlier mechanical cuts having higher leaf N continued but differences were not significant.

In 2016 the later pruned plots generally had lower P, K, Ca and Mn but higher B in the leaves and these results were significant.

Fruit dry matter

Dry matter (DM) was not assessed in 2012, 2013 or 2014.

In 2015 the highest DM recorded was for 12 Leaf NIP (13.7%) and the lowest for 6 Leaf IP (12.9) but differences were not significant.

In 2016, there were significant differences, generally Winter Hand, Pink Bud and the IP sub treatments had higher DM. All treatments had above 12% DM.

Final Conclusion 2012 – 2106

The significant differences in growth response to pruning at the different crop growth stages are consistent through the years and must be taken into account by growers contemplating mechanical pruning. The trial orchard was not vigorous and it should be noted that differences in growth response and yield could be much greater in orchards that are stronger. Where tree control is the major consideration, in vigorous orchards delayed pruning is advised as later timings have shown significant advantages for growth control. Where trees are well controlled and not vigorous the timing at which pruning is carried out appears to be less critical in terms of yield, but growers must be aware that more regrowth results from Winter Hand Pruning and cuts close to blossom.

It is important to judge when to prune by a definitive growth stage rather than by a calendar date and this will depend on the climatic conditions in each year and desired outcome of Fruit Wall management e.g. any reduction of vigour needed to be achieved. Regular leaf counts should be undertaken to establish the desired stage since in this trial periods between growth stages were very variable. As with all pruning interventions it is critically important that growers and their staff assess trees and orchards each year and understand the implications of the degree and the timing of pruning management, in terms of effects on yield, growth and fruit bud development. Growers should be flexible and accurately time any Fruit Wall cuts based on the needs of the orchard rather than mechanically prune every year at a prescribed time (e.g. every year at pink bud or at a certain leaf stage) or alternatively decide not to prune at all in a season, as appropriate. Inter-tree pruning requirements should be considered and will need to be done regularly once the orchard reaches maturity and in established orchards.

In the first year of the trial the volume of cropping wood in the mechanically pruned plots was reduced by the treatments. Less leaf canopy removed in summer pruned plots in later years could account for differences between treatments. As the trees have responded more fruit wood has built up within the canopy behind the mechanical cut and the Fruit Wall trees are

now better furnished resulting in more cropping within the narrower tree profile. Winter Hand treatments have continuously had higher yields than any Fruit Wall treatment although Pink Bud or 9 Leaf NIP are the least different alternatives.

The fact that the adjusted yield for 9 Leaf NIP increased in the 2016 season which had higher than average temperatures in August and September plus low rainfall between July and October suggest that this Fruit Wall timing could be a useful management tool during challenging seasons where maintaining fruit size and colour are important but further validation would be required.

Irrigation is critical at high planting densities otherwise fruit size and quality may deteriorate. Growers will need to ensure adequate irrigation especially during seasons with low rainfall / higher than average temperature to ensure adequate fruit size and maintain sufficient regrowth. Extra fertigation and mulching should also be considered in particular for any weak areas.

The general trend downwards in fruit size from 2014 to 2016 suggests that, whilst thinning practices were similar in each year and fruit size in 2016 was generally smaller due to the adverse weather conditions, the quality of bud wood could have been affected by the strict application of the mechanically pruned treatments at the same growth stage each year.

The tree architecture of the fruit wall system has the potential to overcome issues such as reduced red colouration, as the trees tend to be narrower than in traditional orchards and result in less shading of the fruit. However, this was not demonstrated in 2016. Without inter pruning trees may get progressively thicker and more shaded which could affect fruit colour (although in 2016 three NIP treatments had better colour). Growers will need to bear in mind that summer husbandry including inter pruning may be required. Consideration of colour improving products in high risk years could also be considered.

Percentage Class 1 was acceptable in all years. Starch and fruit firmness were not affected by any of the treatments and dry matter accumulation was acceptable in the two years tested.

Whilst BRIX^0 levels were generally low in all years, fruit was harvested early and sugars would improve in store. Mechanical pruning removes a relatively large amount of leaf and this is probably responsible for reductions in BRIX^0 seen in some years on later pruned treatments. Dry matter levels can also be reduced by late mechanical pruning treatments. This will need to be considered by growers with low BRIX^0 / dry matter orchards planning on using the system as part of their pruning strategy.

Whilst the differences in leaf mineral analysis did not appear to have any detrimental effect on yield or Class 1, growers should take regular leaf samples and be prepared to apply some foliar feed for micro and macro nutrients as required. Amelioration for low P, K, Ca and Mn may be required if choosing to prune after Pink Bud or to improve BRIXº if orchards have a problem since Low K may lead to decreased BRIXº (Nava et al 2008).

Fruit Wall managed trees have a narrow profile and may be suited to narrower alleyways e.g. 3.0m rather than 3.5m as in this trial. Growers may consider increasing the density for newly planted orchards which would increase trees per hectare (from 5714 to 6667 if planted at 0.5m) and maximise the yield efficiency of orchards managed using the Fruit Wall system as part of an integrated approach.

Following discussions at the AHDB Open Days, some growers in Kent are applying mechanical pruning techniques including on Gala and in Bramley production where anecdotal evidence suggests it is successful. Growers also consider that Braeburn may be a more suitable variety due to its habit and to assist in management of biennial bearing.

Pruning times per hectare were reduced for the Fruit Wall treatments when compared to the standard Winter Pruning in this trial.

New intensive orchard systems are simpler and easier to prune than lower density traditional orchards. Commercial pruning costs are reduced for mechanical pruning compared to hand pruning.

As detailed in the Financial Benefits, using mechanical pruning methods as part of a commercial pruning programme may be a more realistic approach than undertaking year on year Fruit Wall cuts at the same growth stage, in particular to ensure that bud wood quality is maintained. Mechanical pruning could be used instead of hand pruning in years where time is limited, labour shortages occur, where there are prolonged poor or challenging weather conditions for canker vulnerable varieties like Gala, for example, and it could also save labour costs eg when National Minimum Wages rise further.

In this relatively short trial of five years, long term trends will not have become apparent. But the consistently lower yields of the Fruit Wall treatments and the higher than envisaged yield reductions compared to hand pruning in the orchard's early fruiting years suggests that this short term trend would continue unless changes were made to the rigid pruning protocol.

Mechanical pruning could be a valuable alternative management tool when employed as part of a customised husbandry programme together with integrating hand pruning.

Further work may be useful in order to assess how to further adapt, develop and implement mechanical pruning as part of a husbandry management programme and to test it on other varieties.

Aims and Objectives 2012 - 2016

i. Project aim

To determine the optimum time to prune fruit wall orchards using Gala as a reference variety.

ii. Project objectives

A. To record growth stages of Gala trees and impose five pruning times by growth stage on a newly established orchard of Gala planted for the Fruit Wall system.
Achieved through assessments and records between 2012 and 2016.

B. To measure the results of each pruning time over 5 cropping years by recording yield and grade out.
Achieved through assessments and records between 2012 and 2016.

C. To record tree growth at the end of each growing season.
Achieved through assessments and records between 2012 and 2016.

D. To assess the influence on fruit maturity from each treatment by measuring starch, sugar and fruit firmness at harvest.
Achieved through assessments and records between 2012 and 2016.

E. To determine the effect of the treatments on the nutritional status of the trees by analysing a sample of leaves and fruits each year.
Achieved through assessments and records between 2012 and 2016.

F. To communicate the results of the trial via grower meetings, HDC News articles and open day(s) at the trial site.
Achieved as detailed under Technology Transfer.

Technology Transfer 2012 – 2016

- Results from 2012-2016 were presented at the FAST LLP member growers' conferences in January 2013 (James Carew), February 2014 (Ivan Velasco, FAST LLP Advisor & Agronomist), February 2015 (Ivan Velasco), February 2016 (Ivan Velasco) and February 2017 (Abi Dalton, Trials Manager).
- Results from 2012 to 2016 were presented at the AHDB Tree Fruit Day in April 2014 (Tim Biddlecombe, Chairman), February 2016 (Abi Dalton, Trials Manager) and on 28 February 2017 (Abi Dalton).
- Articles for The Fruit Grower magazine were submitted in 2013 and the AHDB Horticulture Week in February 2016 and February 2017 for publication.

- Summaries of the trial were placed in the AHDB Tree Fruit Review magazine in 2013 and 2014.
- Open Days were held in August 2012, 2014 and 2016 for growers to view the site and discuss the project.
- A paper was submitted to the ISHS and a presentation made at the Orchard Systems XI Symposium held in Bologna in September 2016 (Tim Biddlecombe).

Acknowledgements 2012 – 2016

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APPENDICES
APPENDIX 1 - Photographs

Photograph series 1 2012 – specialist pruning equipment

Photograph series 2 2013 – Winter Hand IP treatment before and after pruning

Photograph series 3 2013 – Pink Bud NIP before and after mechanical pruning

Photograph series 4 2014 – 6 Leaf before and after mechanical pruning


Photograph series 5 2015 - 9 Leaf IP before and after mechanical pruning


Photograph series 6 2014 - 12 Leaf before and after mechanical pruning


Photograph series 7 2016 - Winter Hand IP and NIP at harvest

APPENDIX 2

Table 12. Leaf Mineral Analysis standard parameters (FAST 2016).

From week 8*	Deficit	Low	Normal	High	Excess
N	<2.2	2.20-2.39	2.40-2.79	2.8-3.0	>3.0
P	<0.17	0.17-0.2	0.21-0.24	0.25-0.28	>0.28
K	<1.16	1.16-1.29	1.30-1.59	1.6-1.8	>1.8
Mg	<0.16	0.16-0.19	0.20-0.25	0.26-0.29	>0.29
Ca	<0.76	0.76-0.84	0.85-0.98	0.99-1.03	>1.03
Mn	<30	30-39	40-70	71-100	>100
B	<16	16-19.9	20-35.9	>35.9	
Cu	<3.0	3.0-4.9	5.0-10.0	>10	
Fe	<85	85-100	101-150	>150	
Zn	<10	10-14.9	14.9-25	>25	

*When week 0 is BBCH stage 54 (mouse ear)