Project Number:	TF 206
Project Title:	Comparison of Different Planting Material for Fruit Wall Orchard Systems for Apple
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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.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Tim Biddlecombe

Chairman

Fruit Advisory Services Team LLP

Signature ..... Date .....

Report authorised by:

Dr William E Parker

Director of Horticulture

The Agriculture and Horticulture Development Board

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GROWER SUMMARY

Headline

- 2017 was the fourth fruiting year and results showed that the 2 Year Old trees again had significantly higher annual yield and also the highest cumulative yield.

Background and expected deliverables

Growers in many countries are actively looking for ways to reduce labour inputs and increase the use of mechanical aids in a range of fruit crops. With a general decline in skilled labour, ease of management is another requirement, but in all these developments it is essential that there is no loss of yield or quality. In fact, an increase in yields will be required to enable growers to maintain profitability.

Following the successful development and commercial uptake of the Concept Orchard (AHDB Horticulture Project TF 151) by many UK growers, further evolution and development of more intensive planting systems is being considered. In TF 151, reference was made to 'Le Mur Fruitier', a newly developed orchard system in France. Further developments of this system have been carried out privately and at the PC Fruit Research Station in Sint Truiden, Belgium. Generally this work has been done in existing orchards that have been adapted to the new pruning regime and generally on varieties not grown in the UK. Results have shown that the principles developed in the work by CTIFL in France can apply in more northern growing areas. However, they need to be adapted to local growing conditions and varieties, as the timing of pruning is critical and specific to individual varieties, whilst the length of the growing season varies in different geographical areas.

Little work has been done on ways of establishing Fruit Wall orchards and which type of tree gives the best results. Conventionally produced trees have a form and structure ideally suited to wider spacings, where a branch framework is necessary, but they can be adapted to be managed in a Fruit Wall planting. However, other tree types may be more suitable, either because they are cheaper and can be planted more intensively at the same cost per hectare, or because they have been specifically grown in the nursery to form a narrow, tall tree potentially giving higher, early yields.

Several specialist nurseries are developing tree types designed and grown especially for Fruit Wall orchards. These include 'grow through trees' from several nurseries, and Bibaum® trees from Mazzoni nurseries. Other nurseries recommend that using a maiden tree or an 8 month tree at a close planting distance can give better results. This project will

provide a comparison of five different tree types using a standard variety/ rootstock and spacing, and provide growers with comparable data to allow them to make informed decisions about the best tree type to use for their own situation.

Summary of the project and main conclusions

Trees were planted and established during 2013. Gala trees (clone Royal Beaut) were sourced from specialist nurseries. The trees were planted in March 2013 at Brogdale Farm, Faversham. The site (soil type: clay loam with flint) had been fallow for at least 10 years. The trees were planted at a distance of 3.5m by 0.8m (except Twin Stem at 1.6m).

The trees were not irrigated during establishment and have not been irrigated during the trial. A standard commercial programme for management of pest and disease, nutrient requirements and foliar feed sprays plus herbicides has been applied since establishment.

The five different tree types selected were:

1. 1 Year 5 + Branches
2. 1 Year Unfeathered
3. 2 Year Old (grow through)
4. Standard Knip
5. Twin Stem

The trial area consists of a randomized complete block with each of the 5 growing systems replicated in 6 blocks (rows):

Table 1. Trial plan.

Twin stem	2 year old grow through	1 Year 5 + branches	1 year unfeathered	Standard knip	1 year unfeathered
2 year old grow through	1 Year 5 + branches	Standard knip	2 year old grow through	1 year unfeathered	Twin stem
1 year unfeathered	Twin stem	2 year old grow through	Standard knip	1 Year 5 + branches	Standard knip
1 Year 5 + branches	Standard knip	1 year unfeathered	Twin stem	2 year old grow through	1 Year 5 + branches
Standard knip	1 year unfeathered	Twin Stem	1 Year 5 + branches	Twin stem	2 year old grow through
Block 1	**Block 2**	**Block 3**	**Block 4**	**Block 5**	**Block 6**

All of the trees were supplied by specialist nurseries in the Netherlands except for the Twin Stem trees, which came from a nursery in Italy. The Dutch trees were grafted onto the dwarfing rootstock M9 (Clone 337), with an equivalent dwarfing rootstock used for the Italian Twin Stem trees.

Each row has 1 plot of 10 trees of each tree type (except for twin stems which have 5 trees but 10 stems), making 300 trees in total on an area approximately 0.09 ha. The middle 8 trees (3 trees for twin stems) were used for recording and sampling and the end 2 trees (1 for Twin Stems) in each plot were guards.

Table 2. Plot layout – except Twin Stems:

	1 guard tree	**8 trees used for recording**	**1 guard tree**

Table 3. Plot layout – Twin Stems:

	1 guard tree	**3 trees used for recording (6 stems)**	**1 guard tree**

During 2013 the trees received minimal pruning by hand to remove excess branches (any that were too strong or too weak) and all fruit was removed in order to ensure that the trees established well.

Growth stages were monitored regularly during early 2016 and shoot growth assessments commenced in May, to establish when to prune at the 9 leaf stage which occurred on 24 June.

Photographs of trees before and after the 9-leaf cut in 2016 cut are included in Appendix 1 at the end of the Science Section of the report.

In July 2016 (after the fruit wall cut), all trees were thinned to 2 fruit per cluster on branches below 1.5m and 1 fruit per cluster on branches above 1.5m. A further quality / crop load thin was also carried out.

Fruit was harvested commencing 12 October 2016 following maturity testing to determine the optimum harvest date, placed into cold store and assessed later for quality and size.

Key results in 2016

- There were statistically significant results in yields – 2 Year Old tree types yielded the most fruit and 1 Year Unfeathered yielded the least fruit.

- Fruit quality in 2016 was good – all tree types achieved over 80% Class 1 except 1 Year 5 + Branches.
- Fruit size in the trial and across the industry in general was small in 2016 due to climatic conditions during fruit development.
- Tree volume decreased for all tree types in 2016. The 2 Year Old trees continue to have the highest volume.

Key results in 2017

2017 was the fourth and penultimate fruiting year.

- There were statistically significant results in yields – 2 Year Old tree types yielded the most fruit and Twin Stem yielded the least fruit.
- Fruit quality in 2017 was again reasonable but affected by frost events at vulnerable growth stages – 1 Year Unfeathered and Standard Knip achieved over 80% Class 1 fruit whilst all other tree types were under 80% and Twin Stem had the lowest of 76.4%.
- Average fruit weight was acceptable in 2017 with all tree types having average single fruit weights of >120g except 2 Year Old (116.5g). 1 Year 5 + Branches had the heaviest average fruit weight of 131.4g.
- Percentage fruit size was acceptable with all tree types having 60% fruit between 60mm and 70mm and <10% fruit under 60mm.
- Tree volume decreased for all tree types in 2017 compared to 2016. The 2 Year Old trees continue to have the highest volume.

Main conclusions to date

2017 was the fourth fruiting year and results showed that the 2 Year Old trees again had significantly higher yearly yield and also the highest cumulative yield. Twin Stem had the lowest yield in 2017 and 1 Year Unfeathered had the lowest cumulative yield. All tree types decreased in volume compared to 2016 but overall yields were greater in 2017 than 2016 for all the tree types and despite damage from frost.

All tree types have reached commercially acceptable Class 1 yields for their age except for Twin Stem. However, Twin Stem had the highest yield efficiency of all tree types.

This trial has demonstrated minimal value to the grower until the fourth fruiting year. However, increased long term returns are possible based on 2017 results and future expected potential yield increases from the best tree type for Fruit Wall systems.

Growers should be able to reduce pruning costs from the reduced labour input required.

Financial benefits

The trees have carried four crops, three of which have been heavy. Most treatments have yielded commercially acceptable marketable quantities with decreased labour inputs in 2017. This trial has so far demonstrated that there is limited potential for increased returns compared to non Fruit Wall managed systems but it is too early to determine conclusive financial benefits. There is potential for reducing pruning costs and skilled pruning labour requirements.

The trial is responding to industry requirements to investigate shortening payback periods and to produce guidance on the cropping potential of different tree types in the early years.

The cost of successfully establishing an intensive orchard is currently up to £28,000 (depending on exchange rates) per hectare (FAST 2018). In particular:

a. The differences in costs of the various tree types available vary depending on type selected and quantity (up to an extra £2.99 per tree or from an extra £165 to £3,300 per hectare - FAST 2018). Some tree types have the potential to increase in volume, vertically and horizontally, much more quickly, leading to increases in early yields.

b. An estimated reduction in yield from a Fruit Wall system of 5% in each of the first four cropping years can reduce net returns by around £3,000 per ha (FAST 2018). However, the actual % reduction for all tree types in the first three cropping years of this Fruit Wall trial has been much greater (up to 87% for 1 Year Unfeathered in 2014 but some of this was due to disease) except for 1 Year 5 + Branches, 2 Year Old and Standard Knip in 2015 (all under 5.5%) - see Table 1. There was improvement in 2017, the fourth cropping year, when three of the tree types yielded more marketable fruit than commercial expectations (1 Year 5 + Branches, 2 Year Old and Standard Knip – between +5.8% and +12.5%). Despite this, based on cumulative marketable yields, the overall reduction in yield for the duration of the trial still falls below this estimate (between -14.3% and -39.8%) - see Table 2. Some of the differences could be attributable to the tree types, orchard and climate conditions. Results from another AHDB funded trial, TF 207 (Determination of the optimum pruning time for fruit wall orchard systems for Gala apple), also demonstrated lower yields than from hand-pruned treatments. Data from 2018 will be added to these calculations in the final report.

Table 1. Percentage difference of yearly Fruit Wall yields compared to commercial

expected yields (25, 35, 45 & 45 t/ha respectively) – shaded cells indicate similar to or greater than estimated Fruit Wall reduction of 5%.

TREE TYPE / YEAR	2014	2015	2016	2017
1 Year 5 + Branches maider	-75.0	-4.4	-30.3	12.5
1 Year Unfeathered whip	-87.1	-32.6	-48.5	-10.2
2 Year Old	-67.9	0.5	-21.4	11.1
Standard Knip	-77.5	-5.3	-25.1	5.8
Twin Stem	-82.4	-21.4	-41.6	-19.1

Table 2. % difference of cumulative Fruit Wall yields compared to commercial expected yields.

TREE TYPE / YEAR	2014	2015	2016	2017
1 Year 5 + Branches maiden	-75.0	-33.8	-32.3	-18.9
1 Year Unfeathered whip	-87.1	-55.3	-52.4	-39.7
2 Year Old	-67.9	-28.0	-25.2	-14.3
Standard Knip	-77.5	-35.4	-31.0	-19.9
Twin Stem	-82.4	-46.8	-44.6	-36.9

c. New intensive orchard systems are simpler and easier to prune than lower density traditional orchards. Depending upon planting distance and hand pruning equipment used, it takes approximately 34 hours (4.5 days) to hand prune one hectare of mature orchard (FAST 2017) compared to three hours for mechanical pruning or a difference of £420 per hectare (Adrian Scripps Ltd 2017). Hand pruning speed is improved if electronic secateurs are used, but these cost around £2,000. Younger trees such as those in this trial would take less time to hand prune (eg three days). Some hand pruning will be needed (eg inter pruning) even where mechanical pruning is used, but net savings of around £6,300 per ha over a 15 year orchard life are envisaged (excluding machinery costs).

d. Anecdotal evidence from experimental plots in Northern Europe suggests that annual yields from Fruit Wall plantings can be around 20 t/ha greater than orchards of a similar density managed conventionally. Mika et al (2016) have recorded an 11.5% increase in yields from mechanically pruned compared to hand pruned trees which would equate to 50 t/ha versus 45 t/ha respectively. The value to the grower of a 5 t/ha increase would be approximately £31,000 net of all post harvest costs over 15 years. In 2017 tree types 1 Year 5 + Branches, 2 Year Old and Standard

Knip achieved marketable t/ha of 50.6, 50.0 and 47.6 respectively - see Table 3. This equates to up to between 12.5%, 11.0% and 5.8% yield increases compared to commercial standard trees of the same age. See Table 1.

Table 3. Marketable yields t/ha per year including standard commercial expectations and 5% expected reduction for Fruit Wall management – shaded cells indicate where Fruit Wall yields have equalled or exceeded standard commercial expectations.

TREE TYPE / YEAR	2014	2015	2016	2017
1 Year 5 + Branches maiden	6.2	33.5	31.4	50.6
1 Year Unfeathered whip	3.2	23.6	23.2	40.4
2 Year Old	8.0	35.2	35.4	50.0
Standard Knip	5.6	33.1	33.7	47.6
Twin Stem	4.4	27.5	26.3	36.4
Standard commercial	25	35	45	45
Standard commercial - 5%	23.75	33.25	42.75	42.75

e. For growers to implement the system they would have to rent or buy specialist pruning equipment. 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 could also be rented out.

f. Continued good technology and knowledge transfer will be needed and possibly further adapted developmental work. This is because the interaction between the Fruit Wall growing system and other orchard management operations (such as use of growth regulators for fruit setting and thinning) could well be different (possibly due to the effects of late pruning on leaf metabolism at a critical time of year during the early fruit development phase). As the leaf to fruit ratio is altered in the Fruit Wall, more attention to crop nutrition and leaf health will be necessary.

Action points for growers

2017 was the fourth fruiting season of the trial. Some significant effects for some parameters are now likely, due to the prolonged Fruit Wall management rather than tree type alone. Cropping wood is increasing within the canopy despite reduced tree volume.

- The Fruit Wall cut was made when nine new leaves had emerged on the current season's growth. Growers regularly need to make random leaf counts to establish the growth stage before making the cut.

- Inter tree pruning was carried out on the trial trees for the first time in spring 2017. Requirements must be considered, and trees will need pruning regularly once grower orchards reach maturity. Only one or two cuts per tree should be required if management is maintained.
- Irrigation is critical at high planting densities, otherwise fruit size and quality may deteriorate. Growers will need to maintain 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 orchard areas.
- Fruit Wall managed trees have a narrow profile and may be suited to growing in narrower alleyways such as 3.0 m rather than 3.5 m, as in this trial. Growers may consider increasing the density in this way for newly planted orchards, which would increase trees per hectare (from 3,571 to 4,167) and to maximise the yield efficiency of orchards managed under the Fruit Wall system.

Other actions points will be determined after the 2018 season when conclusions are made as to the most suitable tree type for Fruit Wall management in terms of early yield build up, highest t/ha and yield of Class 1 fruit plus optimum returns. Results to date suggest that 2 Year Old, 1 Year 5 + Branch and Standard Knip trees are leading in this regard. The difference between the highest yielding tree type per hectare (2 Year OId) and 1 Year Unfeathered (the lowest) is similar over the last four years. The yield difference between 2 Year Old and Twin Stem is increasing. However, there may be scope for planting Twin Stem and 1 Year Unfeathered trees at higher density (narrower alley width) or converting established orchards to the Fruit Wall management system, since they have higher yield efficiency compared to other tree types.

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 1 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 and the mechanisation of pruning are now considered as options in commercial practice in the UK but they require 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 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 a 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 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) demonstrate in their study that the percentage of fruit with acceptable colour was reduced with increased planting densities. Red colouration is an indicator of fruit quality and, therefore, as planting density increases the percentage of Class 1 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 will be 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 both the quality and the quantity. There tends to be negative correlation between vegetative growth and flower bud formation and so 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 re growth and flower bud formation. This is also true for other crops such as cherry - 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 the bud behind the cut will form a shoot, reducing flower bud formation. However, if the cut is made too late the buds do not have enough time and resources to form a fruit bud and will then remain vegetative. 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.

The aim of the trial is to compare different planting material for Fruit Wall orchard systems for Apple by assessing performance (yield and grade out) and tree volume.

Materials and methods

The six year trial was established in 2013.

Gala trees (clone Royal Beaut) were sourced from specialist nurseries.

The trees were planted in March 2013 at Brogdale Farm, Faversham.

The site, soil type clay loam with flint, had been fallow for at least 10 years.

The trees were planted at a distance of 3.5m by 0.8m (except Twin Stem at 1.6m).

A post and wire system with bamboo canes supports the trees.

The trees were not irrigated during establishment and have not been irrigated during the trial.

A standard commercial programme for management of pest and disease, nutrient requirements and foliar feed sprays plus herbicides has been applied since establishment.

The five different tree types selected were:

1. 1 Year 5 + Branches
2. 1 Year Unfeathered (whip)
3. 2 Year Old (grow through)
4. Standard Knip
5. Twin Stem

The trial area consists of a randomized complete block with each of the 5 growing systems replicated in 6 blocks (rows):

Table 4. Trial plan.

Twin stem	2 year old grow through	1 Year 5 + branches	1 year unfeathered	Standard knip	1 year unfeathered
2 year old grow through	1 Year 5 + branches	Standard knip	2 year old grow through	1 year unfeathered	Twin stem
1 year unfeathered	Twin stem	2 year old grow through	Standard knip	1 Year 5 + branches	Standard knip
1 Year 5 + branches	Standard knip	1 year unfeathered	Twin stem	2 year old grow through	1 Year 5 + branches
Standard knip	1 year unfeathered	Twin Stem	1 Year 5 + branches	Twin stem	2 year old grow through
Block 1	**Block 2**	**Block 3**	**Block 4**	**Block 5**	**Block 6**

All of the trees were supplied by specialist nurseries in the Netherlands except for the Twin Stem trees, which came from a nursery in Italy. The Dutch trees were grafted onto the dwarfing rootstock M9 (Clone 337), with an equivalent dwarfing rootstock used for the Italian Twin Stem trees.

Each row has 1 plot of 10 trees of each tree type (except for twin stems which have 5 trees but 10 stems), making 300 trees in total on an area approximately 0.09ha. The middle 8 trees (3 trees for twin stems) were used for recording and sampling and the end 2 trees (1 for Twin Stems) in each plot were guards.

Table 5. Plot layout – except Twin Stems:

	1 guard tree	**8 trees used for recording (8 stems)**	**1 guard tree**

Table 6. Plot layout – Twin Stems:

	1 guard tree	**3 trees used for recording (6 stems)**	**1 guard tree**

During 2013 the trees received minimal pruning by hand to remove excess branches (any that were too strong or too weak) and all fruit was removed in order to ensure that the trees established well.

During the winter of 2016/2017 trees were thoroughly inter pruned (2 to 4 cuts per tree). Strong overlapping branches were removed from the upper canopy. Any very strong or overlapping branches were removed from the lower canopy.

During pruning canker damage was noticed in the trial plot. Any diseased material was removed. Disease presence was most prevalent in the Twin Stem trees where a number of stems were cut down (and averages in calculations amended accordingly).

Other disease pressure within the orchard was moderate to low - Scab (*Venturia inaequalis*) and Powdery Mildew (*Podosphaera leucotricha*). Disease pressure on the rest of the site was moderate to low for Scab and moderate to high for Mildew.

There were severe, long lasting and repetitive frost events at the FAST site in April and May 2017 and affecting the trial plot during vulnerable early growth stages.

Growth stages were monitored regularly during early 2017 and shoot growth assessments commenced on 17 May in order to establish when to prune at the 9 leaf stage which occurred on 7 June.

On 9 June 2017 following the fruit wall cut, all trees were thinned to 2 fruit per cluster on branches below 1.5m and 1 fruit per cluster on branches above 1.5m.

Fruit was harvested commencing 13 September following maturity testing to determine the optimum harvest date, placed into cold store and assessed later for quality and size.

Assessments

In order to determine the correct date to carry out the Fruit Wall cut at the 9 leaf stage, initial assessments of extension growth were made at the beginning of May 2017. Detailed leaf counts commenced on 17 May. One shoot on both sides of each tree or stem was assessed (20 shoots per plot). Average numbers of leaves were calculated and are shown in Table 7.

Table 7. Leaf counts 2017 – average number of leaves.

Date/Tree Type 2017	1 Year 5 +	1 Year Unfeathered	2 Year Old	Standard Knip	Twin Stem	Overall
17-May	5.5	5.2	5.7	5.5	5.4	5.4
23-May	6.5	6.2	6.6	6.8	6.4	6.5
26-May	7.6	7.3	7.6	7.5	7.8	7.6
01-Jun	9.0	8.7	9.3	9.0	9.2	9.0
06-Jun	9.7	9.3	10.3	10.4	10.4	10.0

The Fruit Wall cut was made after the shoot extension growth had reached a mean of 10 leaves. The branches were cut back by hand (simulating a mechanical cut) to a maximum length of 40cm each side at the base of the tree and 20cm at the apex (giving a total width per tree of 80cm and 40cm respectively).

The total yield (kg) was recorded in each plot at harvest commencing 13 September 2017. Average yield per tree and average yield per stem were calculated. A random sample of 100 fruits from each plot was collected at harvest, placed in cold storage and measured during the autumn for fruit size and quality (Class 1; Class 2 and Waste). The average fruit weight (g) was calculated. The percentage of total yield by size category was calculated together with percentages of fruit within each class category (weight (g)).

Height and spread were measured during the autumn of 2017 and tree volume calculated. NB – each twin stem tree was treated as 2 trees and height and spread for each stem measured separately (making 6 in total rather than 8 for the other tree types).

Yield efficiency was calculated being an estimation of the tree productivity per canopy area. In this trial it has been calculated by dividing yield (t/ha) by volume (m^3).

Statistical Analysis

Statistical analysis was carried out using Analysis of Variance (ANOVA) and multiple range tests (MRTs) used to determine whether the differences between individual treatments were statistically significant. Charts are shown with standard error bars (where applicable) and the results of the MRTs are indicated by letters (homogenous groups) where statistically significant effects were shown (and where the P value = < 0.05).

Results

Yield

Yield data was recorded following harvest commencing 13 September 2017.

Table 8. Total yield per tree type, average yield per tree and per stem (kg) 2017:

Tree Type/kg 2017	Total Yield Per Tree Type kg	Average Yield per Tree kg	Average Yield per Stem kg
1 Year 5 + Branches	671.1	14.9	14.9
1 Year unfeathered	545.4	11.9	11.9
2 Year old	696.3	15.1	15.1
Standard Knip	593.2	14.1	14.1
Twin Stem	364.8	22.1	11.1

Table 9. Tonnes per hectare by year:

Tree type/year	t/ha 2014	t/ha 2015	t/ha 2016	t/ha 2017
1 Year 5 + Branches	14.0	35.9	35.0	53.3
1 Year unfeathered	5.3	26.1	25.7	42.3
2 Year old	19.0	37.4	38.5	54.1
Standard Knip	11.9	36.1	35.8	50.4
Twin Stem	8.1	29.0	28.4	39.5

Total yields for all plots for each tree type was between 364.8 kg (Twin Stem) and 696.3 kg (2 Year Old). 2 Year Old trees had significantly higher total yields than all other treatments except 1 Year 5 + Branches. Twin Stem had significantly lower yields than all other treatments. See Table 8 and Figure 1.

Per tree, however, the Twin Stem trees had the highest average yield of 22.1 kg (since they have two stems instead of one). The lowest average yield per tree was 11.9 kg for 1 Year Unfeathered trees. All average yields per tree had increased compared to 2016. There

were statistically significant differences and homogenous groups remained the same as for 2016. See Figure 2.

Per stem the highest yields were for 2 Year Old trees (15.1 kg) and the lowest for Twin Stem trees (11.1 kg). 1 Year Unfeathered and Twin Stem had significantly lower yields per stem than the other treatments. See Figure 3.

There were significant differences in total yields (t/ha) between tree types in 2017 where 2 Year Old trees yielded 54.1 t/ha and Twin Stem 39.5 t/ha. See Table 9 and Figure 4.

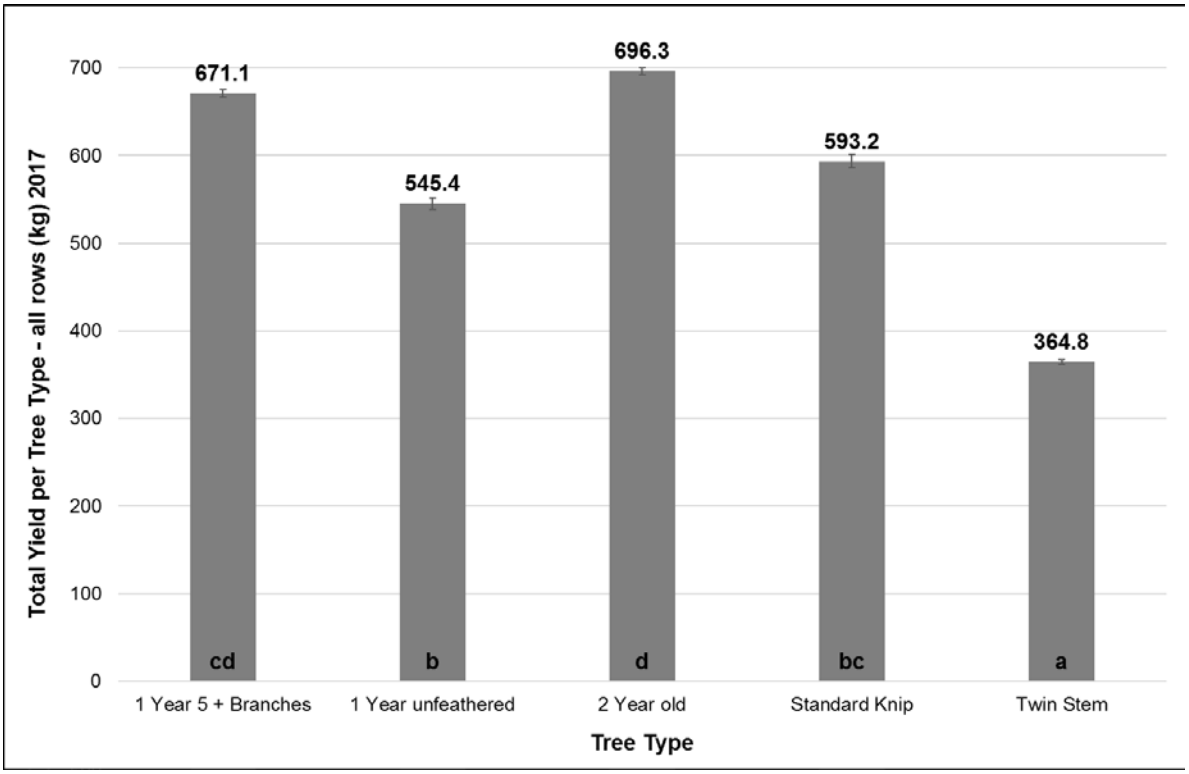

Figure 1. Total Yield per Tree Type (kg). Results with different letters are significantly different from one another (P=<0.001).

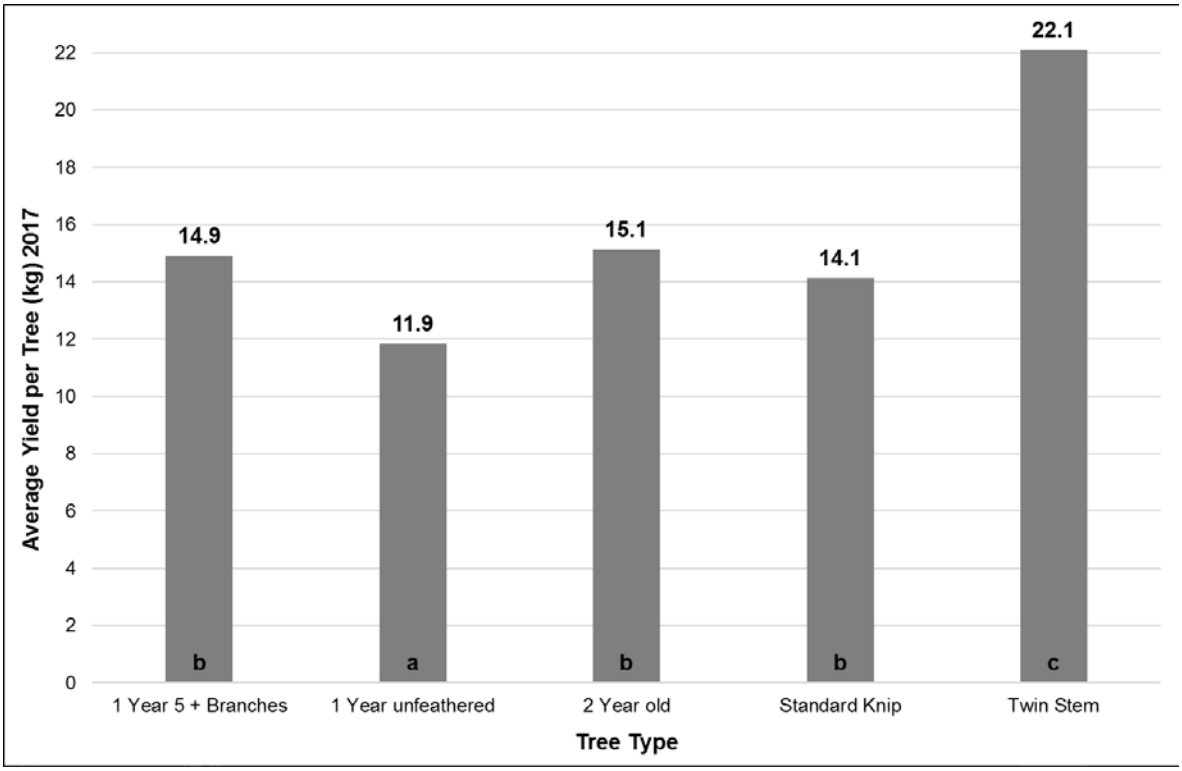

Figure 2. Average Yield per Tree (kg). Results with different letters are significantly different from one another (P=<0.001).

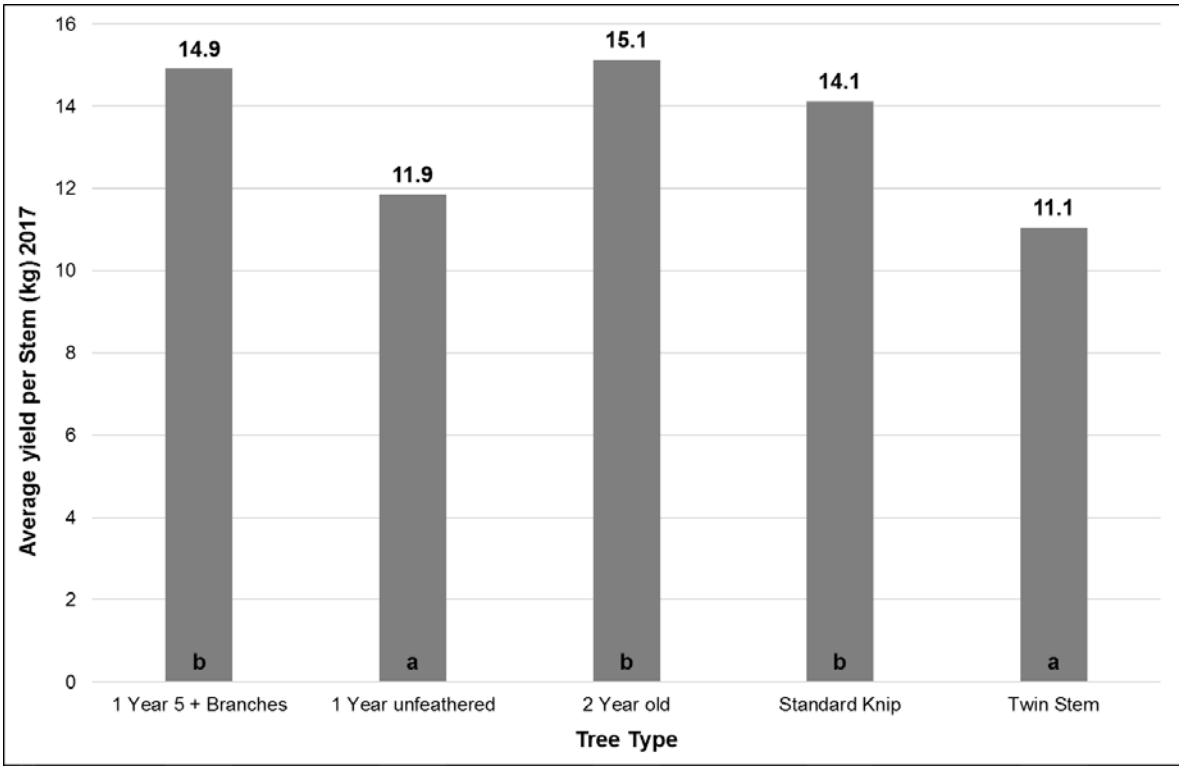

Figure 3. Average Yield per Stem (kg). Results with different letters are significantly different from one another (P=0.002).

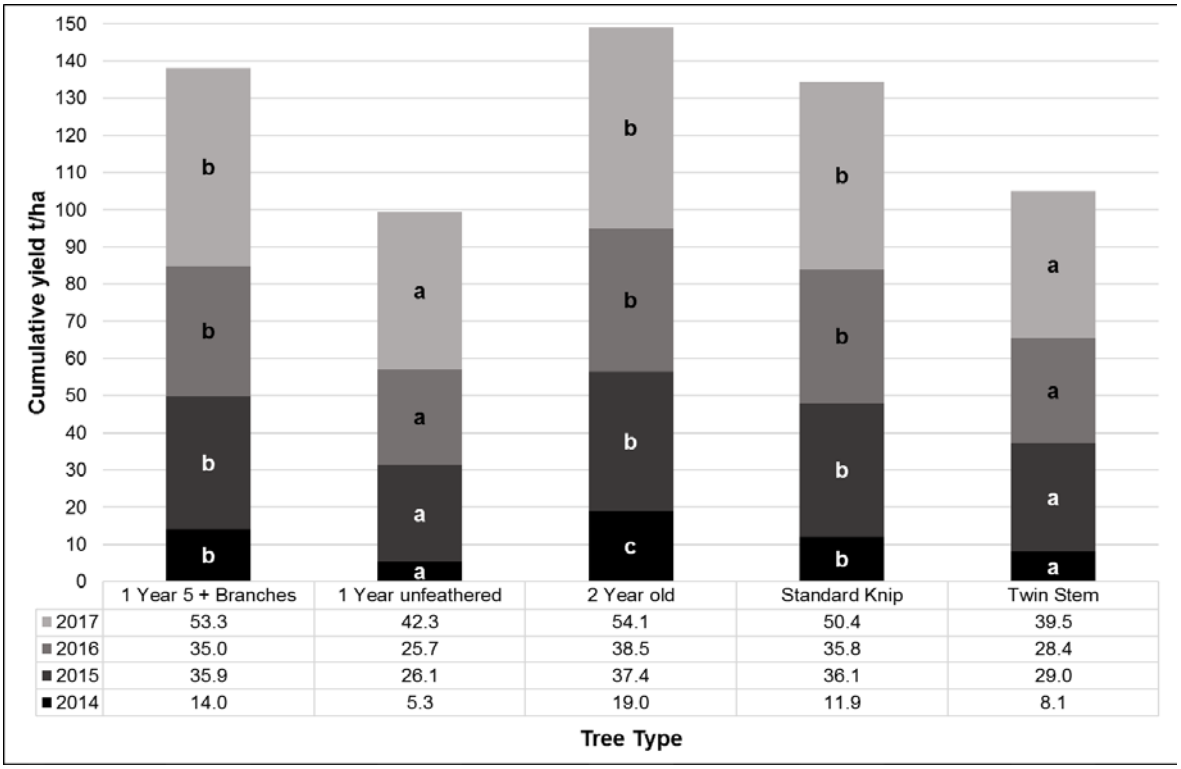

Fig 4. Cumulative Yield tonnes per hectare 2014 to 2017. Results with different letters are significantly different from one another (2017, lightest grey, P=0.002).

Quality (class)

Quality assessments were made after harvest during the autumn of 2017.

Table 10. % Class 1, Class 2 & Waste by Fruit Weight;

Class/Type 2017	1 Year 5+ branches	1 Year Unfeathered	2 Year Old	Standard Knip	Twin Stem
Class 1	79	82.6	78.6	80.4	76.4
Class 2	16.1	12.8	13.9	14	15.8
Waste	4.9	4.6	7.6	5.7	7.8

Class 1 fruit % was highest for 1 Year Unfeathered (82.6%) and lowest for Twin Stem (76.4%). See Table 10 and Figure 5.

Class 2 fruit was highest for 1 Year 5 + branches (16.1%) and lowest for 1 Year Unfeathered (12.8%). Most fruit was downgraded to Class 2 due to russet and disease. See Table 10 and Figure 5.

Percentage Waste fruit was highest for Twin Stem (7.8%) and lowest for 1 Year Unfeathered (4.6%). Most fruit was downgraded to Waste due to size or frost damage. See Table 10 and Figure 5.

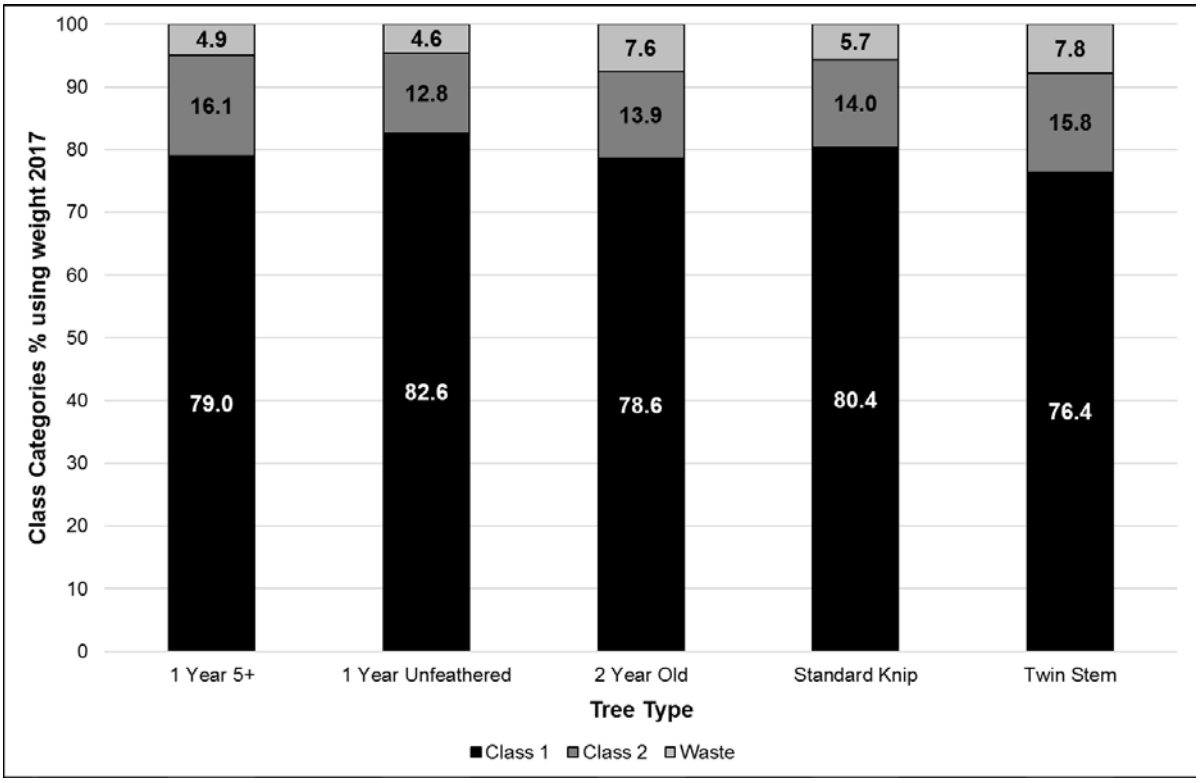

Figure 5. Class Categories % using weight.

Fruit weight

Average fruit weight was calculated from 100 fruit randomly sampled at harvest.

Table 11. Average Fruit Weight (g):

Tree Type / Parameter & Year	Average fruit weight (g) 2017	Average fruit weight (g) 2016	Average fruit weight (g) 2015	Average fruit weight (g) 2014
1 year 5 + branches	131.4	96.5	107.0	132.8
1 year unfeathered	121.7	100.7	115.1	130.3
2 year old	116.5	94.5	108.7	135.1
Standard knip	123.5	103.7	111.9	128.5
Twin stem	120.9	100.0	119.8	147.7

Average fruit weight in 2017 was between 131.4g (1 Year 5 + Branches) and 116.5g (2 Year Old). Unlike 2016, there were no statistically significant differences in fruit weight between treatments in 2017. See Table 11 and Figure 6.

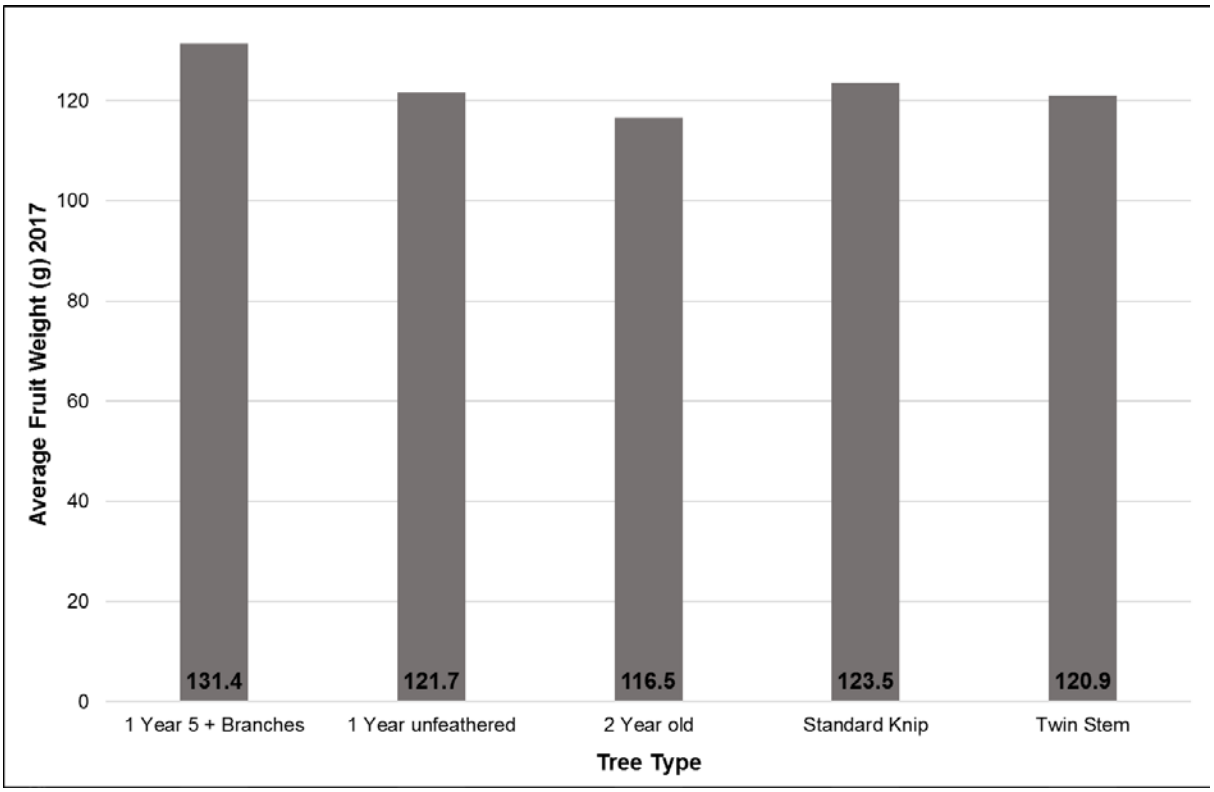

Figure 6. Average Fruit Weight (g). No significant effects in 2017.

Fruit Size

Fruit was assessed for size after harvest during the autumn of 2017.

Table 12. Class 1 - % fruit by weight within size categories:

Size/tree type 2017	1 Year 5+	1 Year Unfeathered	2 Year Old	Standard Knip	Twin Stem
<60 mm	8.4	6.3	7.5	7.3	6.5
60-65mm	32.8	24.6	35.2	24.3	33.5
65-70mm	34.2	42.3	37.7	39.2	34.3
70-75	19.6	21.1	16.3	23.2	21.8
>75mm	5.0	5.8	3.3	6.0	4.0

2 Year Old had the highest combined percentage of C1 fruit sized 60mm to 70mm (72.9%) and Standard Knip the lowest (63.5%).

1 Year 5 + Branch trees had the highest percentage of fruit under 60mm (8.4%) and 2 Year Old had the lowest (6.3%).

Unlike 2016, all tree types had some fruit over 75mm in 2017.

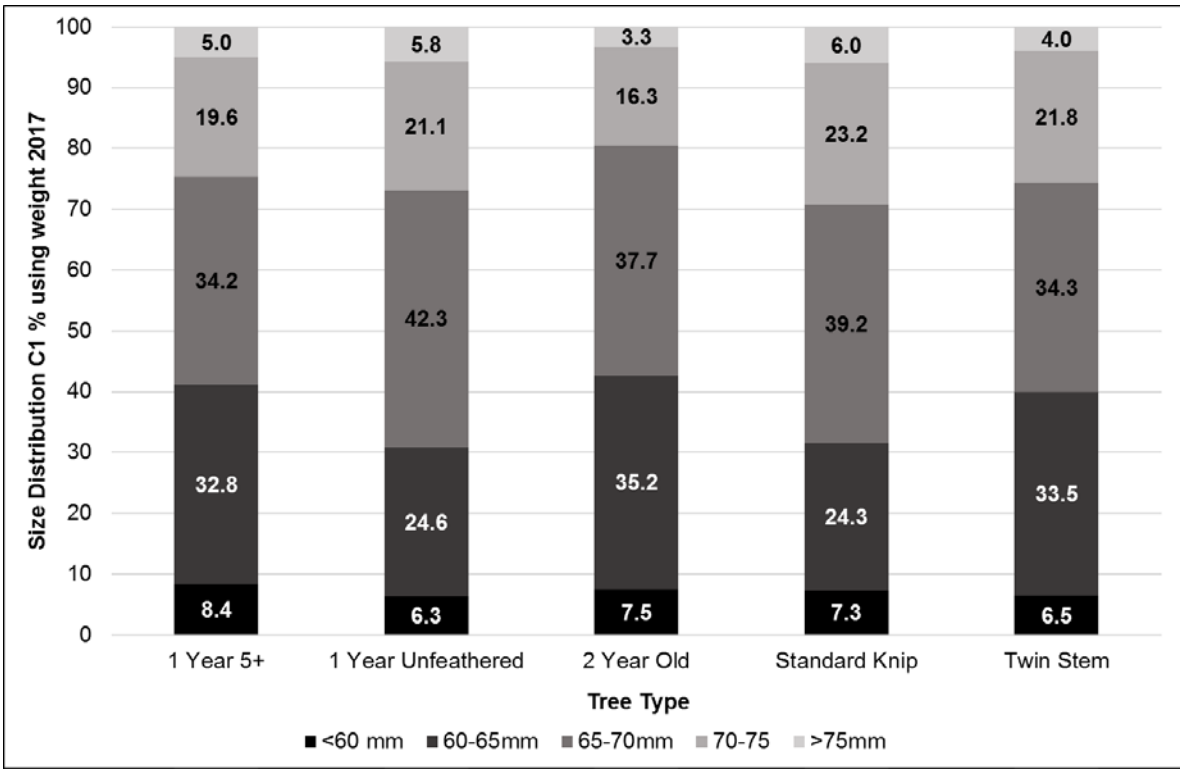

Figure 7. Size Distribution C1 % using weight.

Tree height, spread and volume

Tree height and spread were measured during the autumn of 2017 and the volume calculated.

Table 13. Tree height, spread and volume:

Treatment 2017	Height cm	Average Spread cm	Average Volume m^3
1 year 5 + branches	273.7	109.5	0.89
1 year unfeathered	260.7	97.0	0.67
2 year old	281.3	117.8	1.04
Standard knip	279.2	113.3	0.95
Twin stem	243.7	96.4	0.62

The average tree height varied between 281.3cm for 2 Year Old trees and 243.7cm for Twin Stems. Results for the average tree height were statistically similar for 1 Year 5 + Branches, 2 Year Old and Standard Knip. Twin Stem trees were significant shorter than all other treatments. See Table 13 and Figure 8.

The average spread varied between 117.8cm for 2 Year Old trees and 96.4 for Twin Stem. Statistically significant differences between spread for tree types were noted – Twin Stem and 1 Year Unfeathered had smaller spreads than all other treatments and 2 Year Old greater than all other treatments except Standard Knip. See Table 13 and Figure 9.

The average tree volume varied between 1.04m^3 for 2 Year Old trees and 0.62m^3 for Twin Stem trees. The same statistically significant differences as for spread were noted for the average tree volume. See Table 13 and Figure 10.

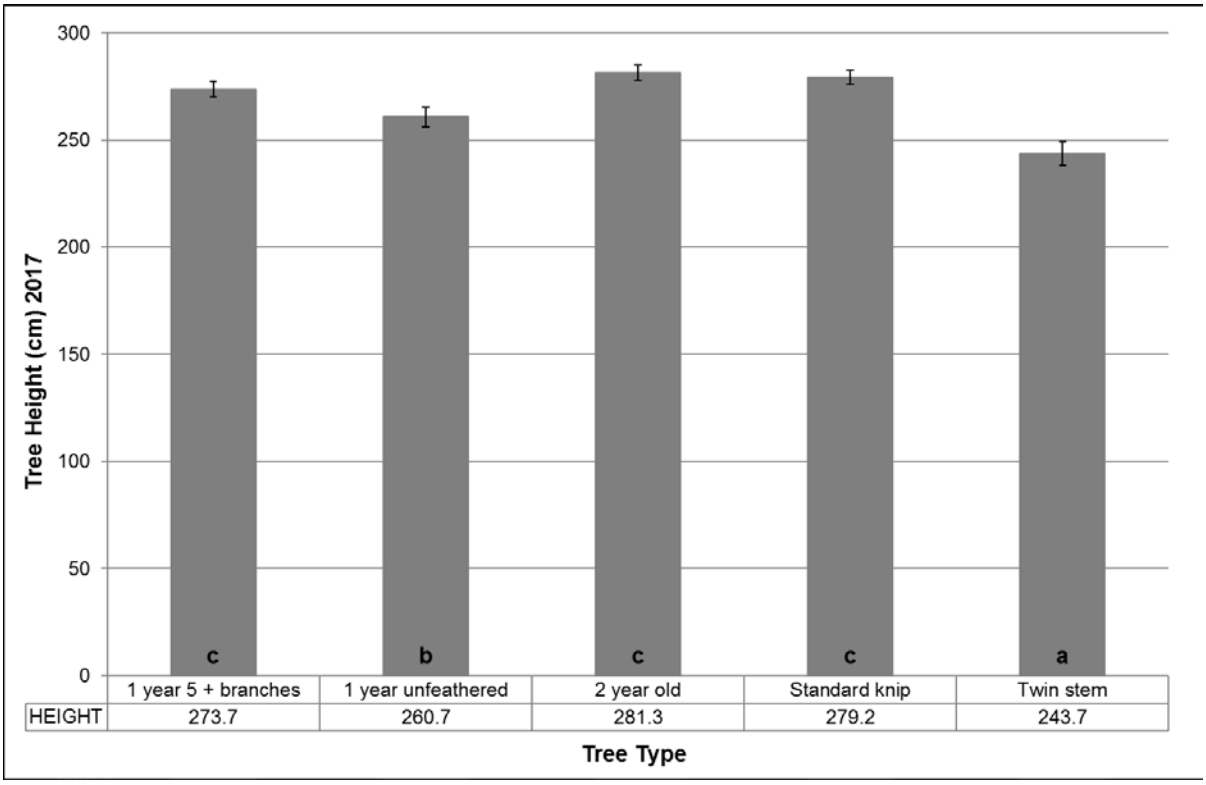

Figure 8. Tree Height (cm). Results with different letters are significantly different from one another (P=<0.0001).

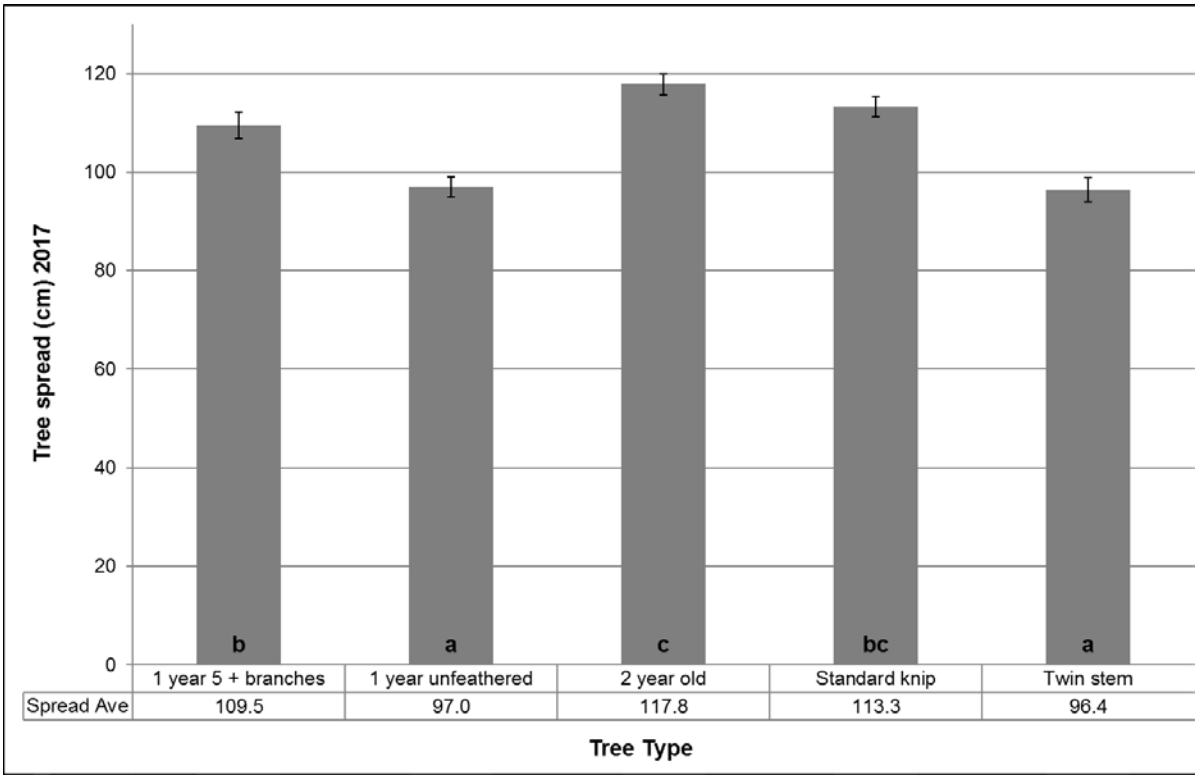

Figure 9. Tree Spread (cm). Results with different letters are significantly different from one another (P=<0.0001).

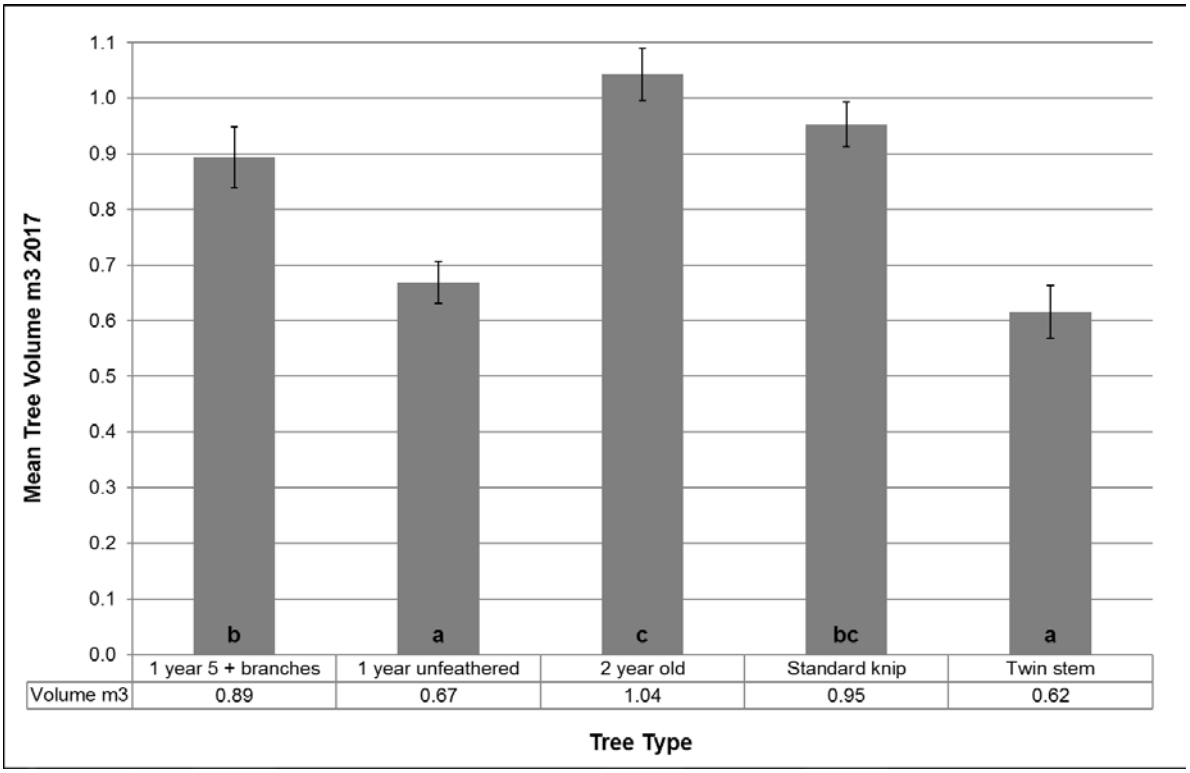

Figure 10. Tree Volume (m³). Results with different letters are significantly different from one another (P=<0.0001).

Yield efficiency

In 2017, the yield efficiency varied between 51.8% (2 Year Old) and 64.1% (Twin Stem).

Table 14. Yield efficiency t/ha:

TREE TYPE / YIELD t/ha EFFICENCY % YEAR	2014	2015	2016	2017
1 year 5 + branches	23.4	25.6	35.0	59.6
1 year unfeathered	17.7	28.9	36.7	63.3
2 year old	27.2	24.9	29.6	51.8
Standard knip	19.9	30.1	32.6	52.9
Twin stem	40.7	36.2	40.5	64.1

Discussion

The growth extension period was 18 days shorter in 2017 compared to 2016 and the fruit wall cut was slightly later.

There were significant effects of tree type on all yield assessments in 2017.

As per 2015 and 2016, total yields between tree types during 2017 were variable. Unlike 2013 – 2016 (when 1 Year Unfeathered had the lowest yield) Twin Stem trees were the lowest yielding trees in 2017. Whilst 2 Year Old trees remain the highest yielding tree type, Standard Knip and 1 Year 5 + Branches yields were again statistically similar in 2017. All tree types except the 1 year Unfeathered and Twin Stem produced >45 t/ha which is expected in a commercial orchard in its fourth fruiting year.

There were increases in yields for all tree types between 2016 and 2017 (>10 t/ha each), despite frost events. Trees had heavy crop loads.

The cumulative total yield profile remains similar between tree types in 2017.

As per 2014 – 2016, numerical differences between the highest and lowest yielding tree type also remain similar in 2017.

Disease pressure in the trials orchard plot was moderate to low in 2017. Class 1 percentages were generally lower than 2016. Only 2 tree types achieved over 80% Class 1 in 2017 but marketable fruit (Class 1 and 2) percentages were above 90% as in 2015 and 2016. Class 2 averages in 2017 were higher than 2016. Average waste percentages in 2017 compared to 2016 were similar except for 1 Year 5 + Branches and 1 Year Unfeathered which were lower. Most Class 2 fruit was due to russet and disease. Most Waste fruit was due to small and oversize fruit or frost damage.

Average fruit weight was acceptable in 2017 and improved from 2016 – >120g for all trees types except 2 Year Old (116.5g). Unlike all previous years, average fruit weight was statistically similar for all tree types.

Average fruit size in 2017 was acceptable and increased from the previous year with very low percentages of fruit <60mm.

All tree types increased in height between 2016 and 2017 except 2 Year Old. All tree types decreased in spread and volume between 2016 and 2017. There were significant effects of tree type on physiological measurements. Tree heights for Twin Stems remain significantly less than all other tree types. Tree spread and volume remain significantly lower for Twin Stem and 1 Year Unfeathered due to delayed overall development of cropping wood.

Twin Stem trees have had the highest yield efficiency in each year of the trial. 2 Year Old has the lowest yield efficiency in each year of the trial except 2014.

Conclusions

- Percentage Class 1 reductions were likely due to frost damage in 2017.
- The speed at which newly planted trees increase in volume and achieve good yields in the first years after planting are crucial to the success of new orchards.
- The rate at which the trees in the Fruit Wall system increased in volume was also reduced in 2017 for the second season running.
- Tree volume in 2017 was probably reduced by the effects of inter tree pruning and disease (Twin Stems) and seasonal growth was suppressed due to the heavy crop load.
- However, the reduction in physical volume in 2017 did not reduce yields indicating that the Fruit Wall management system is working and the timing of the cut is optimal – regrowth is limited and fruit bud formation behind the pruning cut encouraged, therefore actually increasing the volume of cropping wood in the maturing trees.
- A different assessment of tree volume such as Leaf Wall Area or Porosity may be a more robust method for estimating and revealing differences between tree types in the development of fruit bud/cropping wood.
- Statistically significant results of various assessments were again observed in 2017.
- Yield variability in the early years between tree types might be predictable but it was expected that differences would be reduced in the penultimate year of the trial.
- It is possible that the responses are due to establishment of the different tree types and (latterly) the pruning effects.
- The lower yields for Twin Stem trees in 2017 may have been a combination of interpruning and disease prevalence (loss of some entire stems).
- The statistically similar fruit weights are likely due to the prolonged Fruit Wall management rather than tree type.
- Despite low tree costs per hectare for 1 Year Unfeathered and predicted higher returns for Twin Stem trees, early results in this trial suggested that they are less suitable for growing in a Fruit Wall system because of slow establishment and lower yields compared to other tree types in the trial and conventionally pruned trees of the same type and age.

- Based on early yields compared with predicted returns and considering the tree costs, 2 Year Old, Standard Knip 2 and 1 Year 5 + Branches may be more suitable for growing in a Fruit Wall system.
- However, whilst Twin Stem and 1 Year Unfeathered trees have statistically lower volumes and yields than the other tree types their higher yield efficiency suggests that they could be grown at reduced alley widths and lower canopy height without yield reductions and there may be potential for converting existing orchards.
- Based on results from this trial to date, there would be minimal value to the grower until the fourth fruiting year, given the consistently lower marketable yields of the Fruit Wall managed trees compared to standard commercial expectations of hand pruned trees.
- However, increased long term returns are possible based on 2017 results and future expected potential yield increases from the best tree type for Fruit Wall systems.
- Growers should be able to reduce pruning costs from the reduced labour input required.
- Labour savings versus net reductions will be examined and results will be concluded at the end of 2018.

Objectives

The objectives have been achieved by following the programme of work and specifically:

A. To select 5 different tree types with potential for use in the Fruit Wall System.
   Achieved during 2012/2013 when trees were planted.
B. To measure the performance of each tree type under the same Fruit Wall management technique over 5 cropping years by recording yield and grade out.
   Partially achieved through assessments and records between 2014 and 2017 and continuing.
C. To measure tree volume by recording height and spread each year.
   Partially achieved through assessments and records between 2014 and 2017 and continuing.
D. To provide growers with guidance on the attributes including cost of establishment and of the different tree types, so that they can make informed decisions with establishing new orchards.
   Partially achieved through assessments and records between 2014 and 2017, reports for 2013 to 2017 and continuing.
E. To communicate the results of the trial via grower meetings, HDC News articles and open day(s) at the trial site.

Achieved via HDC news articles in 2014, 2015, 2016 and 2017, at the FAST Members Conferences in 2015, 2016 and 2017 plus at AHDB Tree Fruit Technical Days in 2016 and 2018. Continues.

Knowledge and Technology Transfer

Results have been presented at the:

- AHDB Tree Fruit Day for Agronomists on 28 February 2018 (Abi Dalton, Trials Manager).
- FAST LLP growers' conference on 2 February 2017 (Abi Dalton, Trials Manager).
- An article for the AHDB Grower magazine was submitted in February 2017 for publication.

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APPENDIX 1 PHOTOGRAPHS AFTER PLANTING

1 Year 5 + Branches

1 Year Unfeathered

2 Year Old

Standard Knip

Twin Stem