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

Managing Partner

Fruit Advisory Services Team LLP

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

Report authorised by:

Dr William E Parker

Director of Horticulture

The Agriculture and Horticulture Development Board

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

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GROWER *SUMMARY*

Headline

- In the second fruiting year of this trial, two year old tree types yielded most fruit overall and more Class 1 fruit, with one year old unfeathered trees the least, although all tree types are developing and filling their space.

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

The trial was established to compare the performance (yield and grade out) of different nursery tree types when planted in an intensive orchard, managed using the Fruit Wall system.

Trees were planted and established during 2013. Records and assessments commenced in 2014 with 2015 being the second fruiting year.

There were statistically significant results in yields - Two year old tree types yielded the most fruit (both total yield and Class 1). One year old unfeathered trees yielded the least fruit.

Fruit quality in 2015 was good.

The trees are starting to fill their space and develop cropping wood and substantial lateral branches. The two year old trees are more advanced in this respect.

Financial benefits

As the trees have only carried two small crops, 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 the industry's needs to shorten payback periods and to produce guidance on the cropping potential of different tree types in the early years.

The cost of establishing an intensive orchard is currently between £22k and £28k per hectare. In particular:

- The differences in cost of the various tree types available is quite small (typically around £0.50 per tree or £1500 per ha), but a reduction in yield of 5% in each of the first four cropping years can reduce net returns by around £3,000 per ha. Some tree types have the potential to fill their space, vertically and horizontally, much more quickly, leading to increases in early yields, whilst others require more inputs in terms of pruning and thinning in order to achieve successful establishment.

- Although new intensive orchard systems are simpler and easier to prune than lower density traditional orchards, it can still take between 25 and 40 man hours to prune a 1

ha orchard. Rates of mechanical pruning are between 1.5 and 2.5 hours per ha depending on planting distance. Some hand pruning will be needed even where mechanical pruning is used but net savings of around £3,000 per ha over a 15 year orchard life are envisaged (net of machinery cost).

- Anecdotal evidence from experimental plots in Northern Europe suggests that annual yields from Fruit Wall plantings can be around 20 tonnes per ha greater than orchards of a similar density managed conventionally. The value to the grower of this increase would be approximately £21,000 net of all post-harvest costs over 15 years.

- For growers to implement the system they would have to rent or buy specialist pruning equipment. Current costs for this type of equipment are in the region of £14,000, but the machine also has the capability of being used for other operations on the farm such as hedge and windbreak cutting.

- There will be a need for good technology and knowledge transfer and possibly further development 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

- 2015 was the second fruiting season of the trial.
- The Fruit Wall cut was carried out when 9 new leaves had emerged on the current season's growth. To determine this growers need to regularly make random leaf counts to establish the growth stage before making the cut.
- Other action points will be determined in future years when it is established which tree type may be most suitable to Fruit Wall management in terms of early yield build up and highest yield of Class 1 fruit.

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 is now being considered as an option for commercial practice in the UK as mechanisation of pruning and other operations (for example thinning) is possible and it requires 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 its extent. 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.

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

The trees were not irrigated during establishment.

A standard commercial programme of foliar nutrition, disease and pest 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) (Figure 1):

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**

Figure 1. Trial plan.

Each row has 1 plot of 10 trees of each tree type (except for twin stems which have 5 trees but 10 stems), (Figure 2 and 3), 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.

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

Figure 2. Plot layout – except Twin Stems

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

Figure 3. Plot layout – Twin Stems:

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 2015 and shoot growth assessments commenced in May in order to establish when to prune at the 9 leaf stage which occurred on 30 June.

Photographs of trees before and after the 9 leaf cut in 2015 cut are included in Appendix 1.

In summer 2015, 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 on 8 October 2015 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 on 6 May 2015. Detailed leaf counts commenced on 21 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 1.

DATE	1 Year 5 +	1 Year Unfeathered	2 Year Old	Standard Knip	Twin Stem	Overall
13 May	2.6	2.3	2.0	2.2	1.9	**2.2**
21 May	2.3	2.5	2.6	2.9	2.2	**2.5**
27 May	3.1	2.8	3.4	3.3	2.9	**3.1**
4 June	5.1	4.6	5.4	5.0	4.9	**5.0**
11 June	7.7	6.3	7.9	8.5	6.2	**7.3**
19 June	8.7	8.5	9.2	9.0	8.8	**8.8**

Table 1. Leaf counts

The Fruit Wall cut was made after the shoot extension growth had reached a mean of 8.8 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 on 8 October 2015. 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 winter of 2015/2016 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).

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 at harvest on 8 October 2015 (Table 2).

TREE TYPE	Total yield per tree type (kg)	Average yield per tree (kg)	Average yield per stem (kg)
1 year 5 +	472.7	10.0	10.0
1 Year Unfeathered	341.9	7.3	7.3
2 Year Old	490.2	10.5	10.5
Standard Knip	465.8	10.1	10.1
Twin Stem	292.2	16.2	8.1

Table 2. Total yield per tree type, average yield per tree and per stem (kg) 2015

The total yield of all plots for each tree type was between 490.2kg (2 Year Old) and 292.2kg (Twin Stem). There were statistically significant results – see Figure 4.

Results for average yields per tree were statistically significant – see Figure 5. The highest average yield per tree was 16.2kg for Twin Stem trees. The lowest average yield per tree was 7.3kg for 1 Year Unfeathered trees.

Differences in results for the average yield per stem were statistically significant – see Figure 6. The highest yields per stem were for 2 Year Old trees (10.5kg) and the lowest for 1 Year Unfeathered trees (7.3kg).

There were significant difference in yields (t/ha) between tree types in 2015 (see Figure 7) where 2 Year Old trees yielded 37 t/ha and 1 Year Unfeathered only 26 t/ha. Cumulative yields also follow the same pattern.

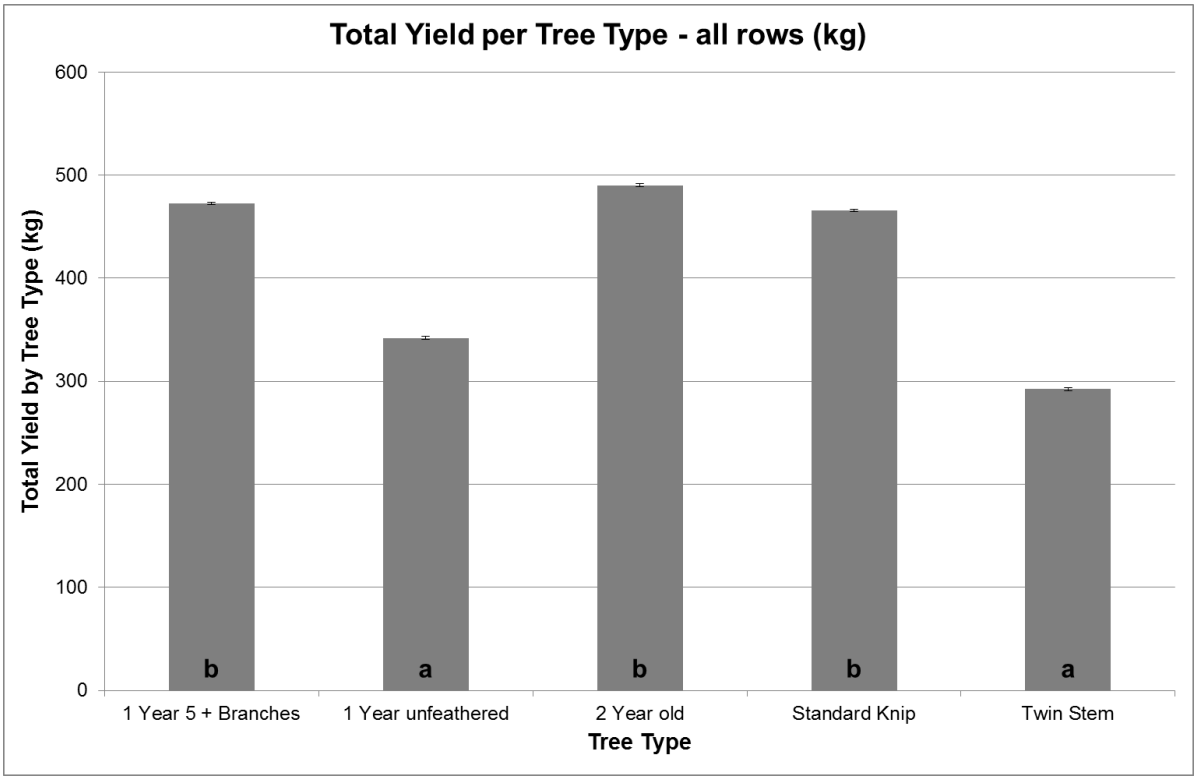

Figure 4. Total Yield per Tree Type (kg). Results with different letters are significantly different from one another (P<0.0001).

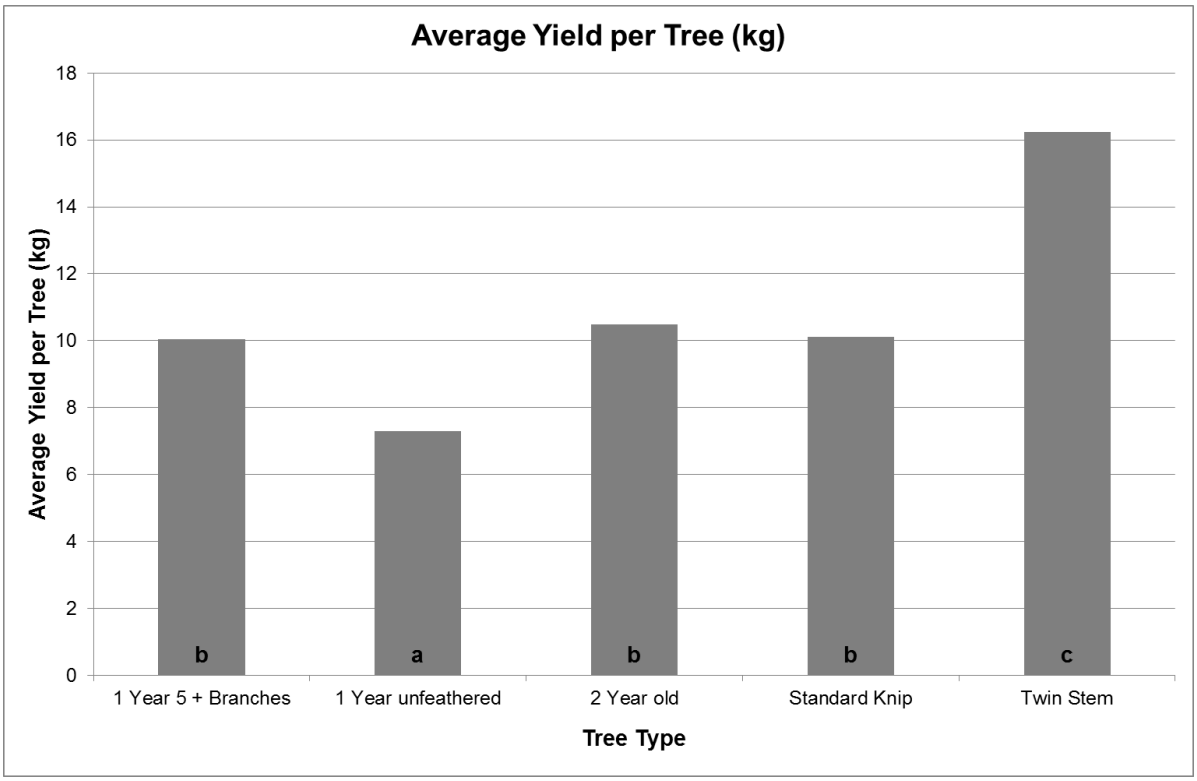

Figure 5. Average Yield per Tree (kg). Results with different letters are significantly different from one another (P=<0.0001).

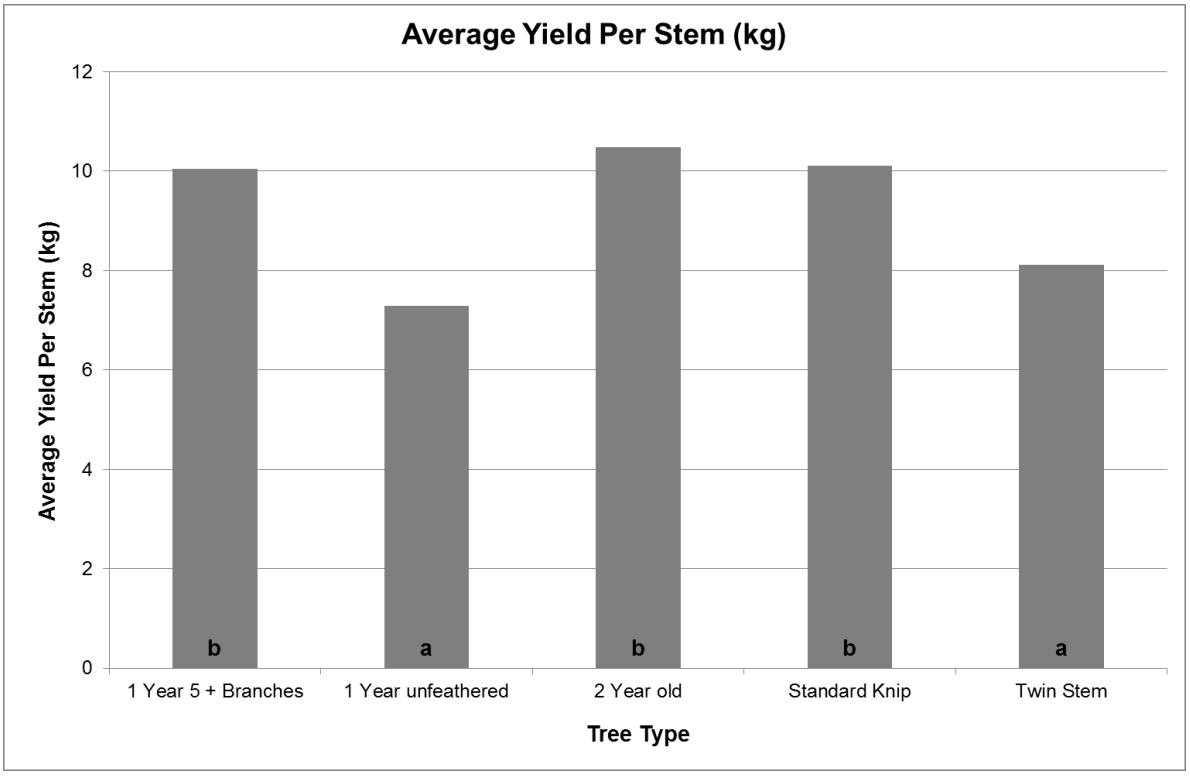

Figure 6. Average Yield per Stem (kg). Results with different letters are significantly different from one another (P<0.0001).

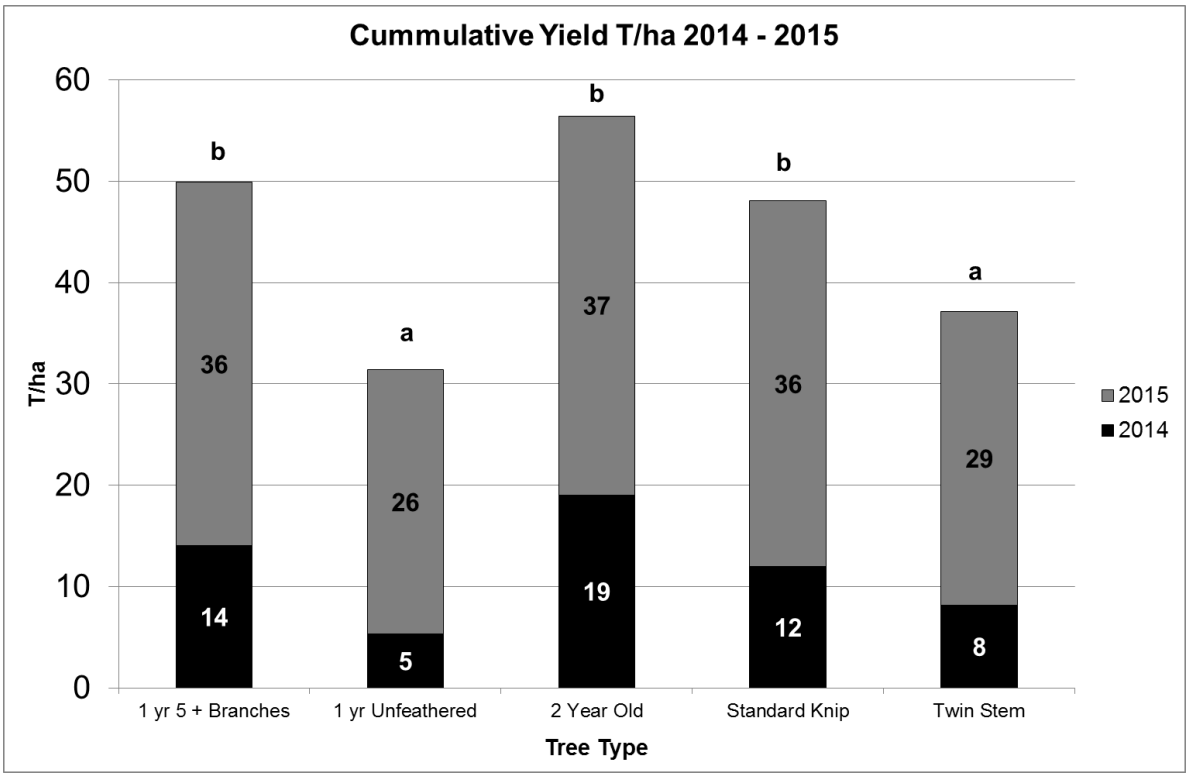

Figure 7. Cumulative Yield tonnes per hectare 2014 and 2015. Results (2015) with different letters are significantly different from one another (P<0.0001).

Quality (class)

Quality assessments were made after harvest during the autumn of 2015, (Table 3).

Class / Type	1 Year 5+ branches	1 Year Unfeathered	2 Year Old	Standard Knip	Twin Stem
Class 1	70.1	65.4	73.3	67.0	68.5
Class 2	23.2	25.1	20.7	24.8	26.4
Waste	6.6	9.4	6.0	8.2	5.1

Table 3. Class 1, Class 2 & Waste - % Fruit Weight.

2 Year Old trees had the highest Class 1 (73.3%) and 1 Year Unfeathered the lowest (65.4%).

Twin Stem had the most Class 2 fruit (24.4%) and 2 Year Old the least (20.7%).

Percentage Waste fruit was highest for 1 Year Unfeathered (9.4%) and lowest for Twin Stem (5.1%), (Figure 8).

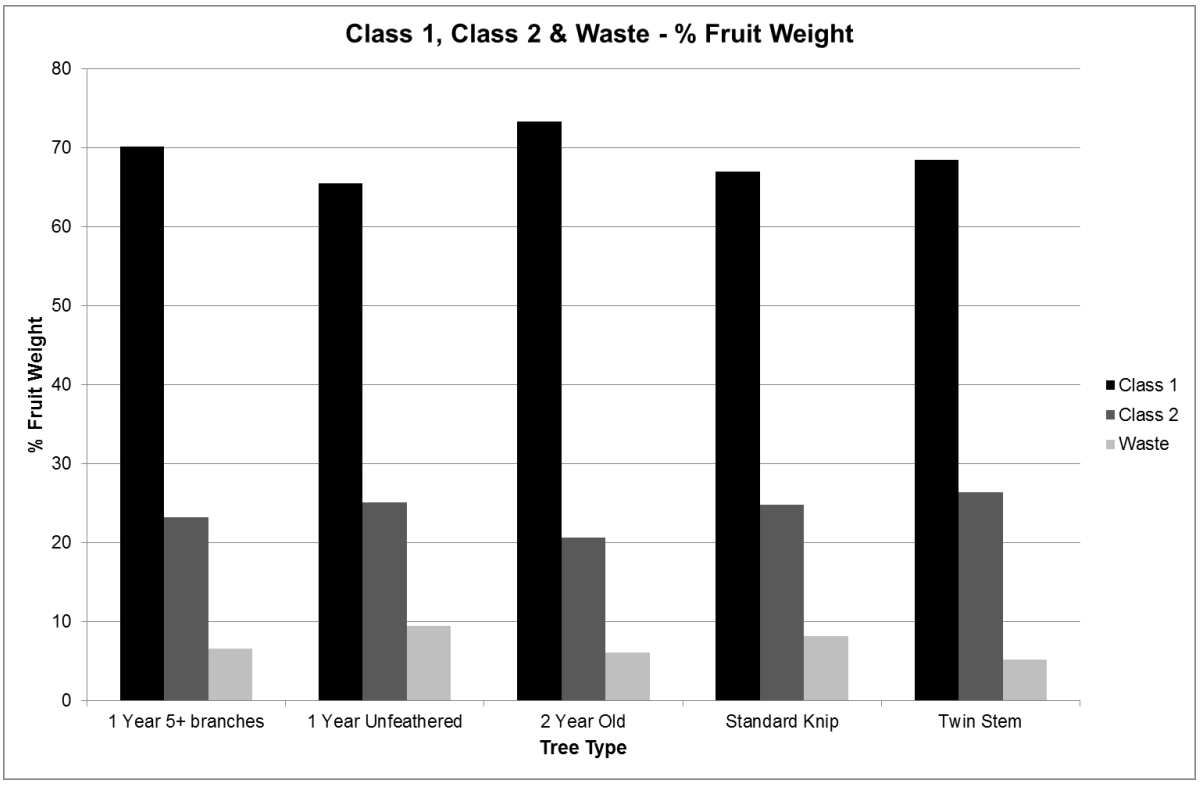

Figure 8. Class 1, Class 2 & Waste - % Fruit Weight.

Fruit weight

Average fruit weight was calculated from 100 fruit randomly sampled at harvest (Table 4).

TREE TYPE	Average fruit weight (g) 2015	Average fruit weight (g) 2014
1 year 5 + branches	107.0 a	132.8
1 year unfeathered	115.1 bc	130.3
2 year old	108.7 ab	135.1
Standard knip	111.9 ab	128.5
Twin stem	119.8 c	147.7

Table 4. Average Fruit Weight.

Average fruit weight in 2015 was between 119.8g (Twin Stem) and 107.0 (1 Year 5 + Branches). Twin Stem fruit weight was significantly different to all other treatments except 1 Year Unfeathered. Both these treatments were significantly different to 1 Year 5 + Branch fruit weights – see Figure 9.

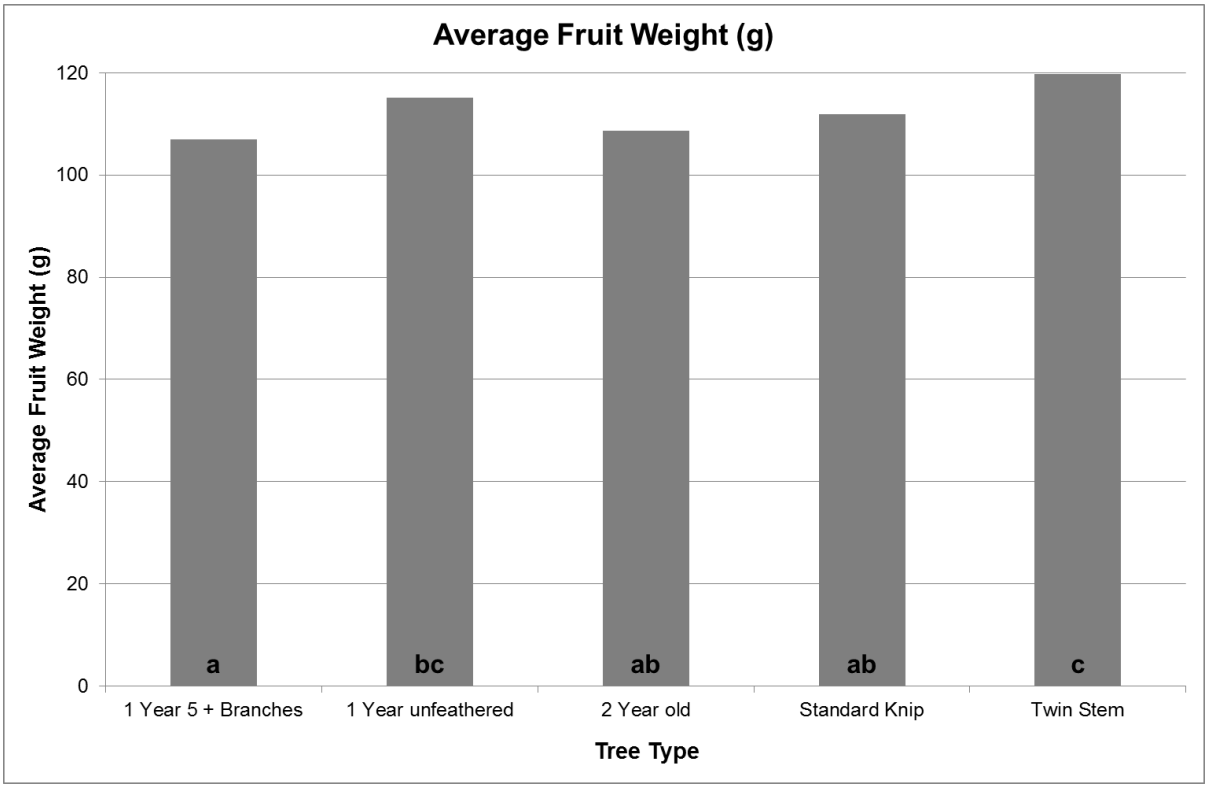

Figure 9. Average Fruit Weight (g). Results with different letters are significantly different from one another (P=0.0139).

Fruit Size

Fruit was assessed for size after harvest during the autumn of 2015, (Table 5).

Size / tree type	1 Year 5 +	1 year unfeathered	2 year old	Standard knip	Twin stem
<60mm	16.1	9.4	17.2	13.1	6.5
60-65mm	37.8	28.0	29.6	32.7	24.9
65-70mm	36.3	45.7	38.8	35.9	44.0
70-75mm	9.0	14.8	12.9	17.0	20.9
>75mm	0.8	2.1	1.5	1.2	3.7

Table 5. Class 1 - % fruit by weight within size categories:

1 Year 5 + had the highest combined percentage of C1 fruit sized 60mm to 70mm (74.1%) and 2 Year Old the lowest (68.4%).

2 Year Old trees had the highest percentage of fruit under 60mm (17.2%) and Twin Stem had the lowest (6.5%).

Twin Stem had the largest percentage of fruit over 75mm by weight within Class 1 yields (3.7%) and 1 Year 5 + Branches the smallest (0.8%), (Figure 10).

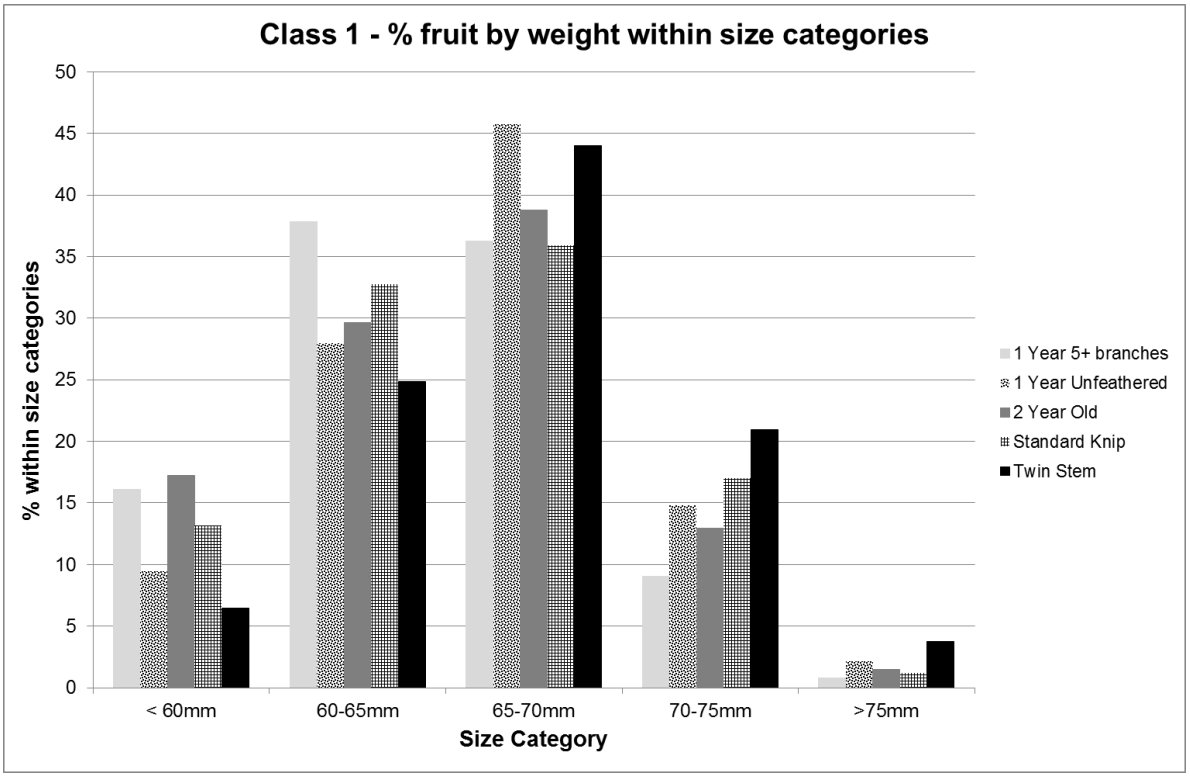

Figure 10. Class 1 - % fruit by weight within size categories.

Tree height, spread and volume

Tree height and spread were measured during autumn/winter in 2015 and the volume calculated, (Table 6).

TREATMENT	Height cm	Average Spread cm	Volume m^3
1 Year 5 + Branches	256.6	142.5	1.4
1 year Unfeathered	232.3	117.1	0.9
2 Year Old	272.0	149.4	1.5
Standard Knip	259.0	139.3	1.2
Twin Stem	223.4	111.4	0.8

Table 6. Tree height, spread and volume.

The average tree height varied between 272.0cm for 2 Year Old trees and 223.4cm for Twin Stems. The differences in the average tree height were statistically significant – see Figure 11.

The average spread varied between 149.4cm for 2 Year Old trees and 111.4cm for Twin Stem trees. Statistically significant differences between spread for tree types were noted – see Figure 12.

The average tree volume varied between 1.5m^3 for 2 Year Old trees and 0.8m^3 for Twin Stem trees. There were statistically significant results between tree types for tree volume – see Figure 13.

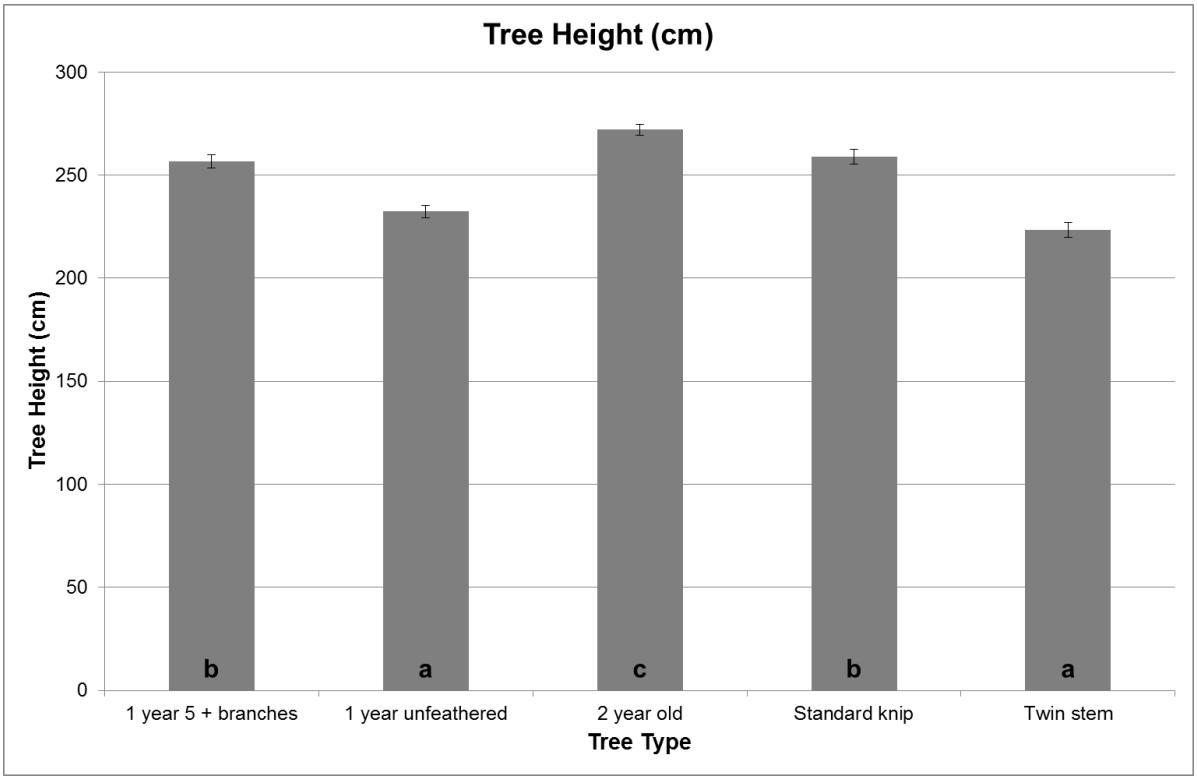

Figure 11. Tree Height (cm). Results with different letters are significantly different from one another (P = <0.0001).

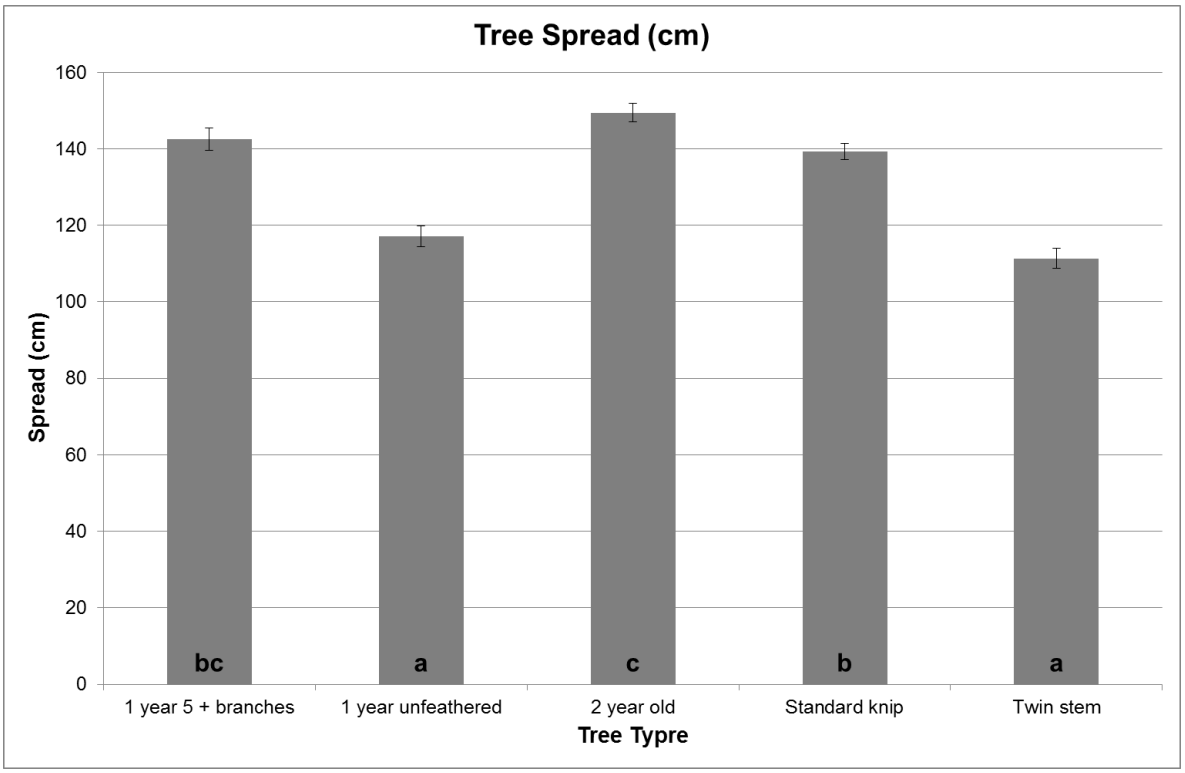

Figure 12. Tree Spread (cm). Results with different letters are significantly different from one another (P = <0.0001).

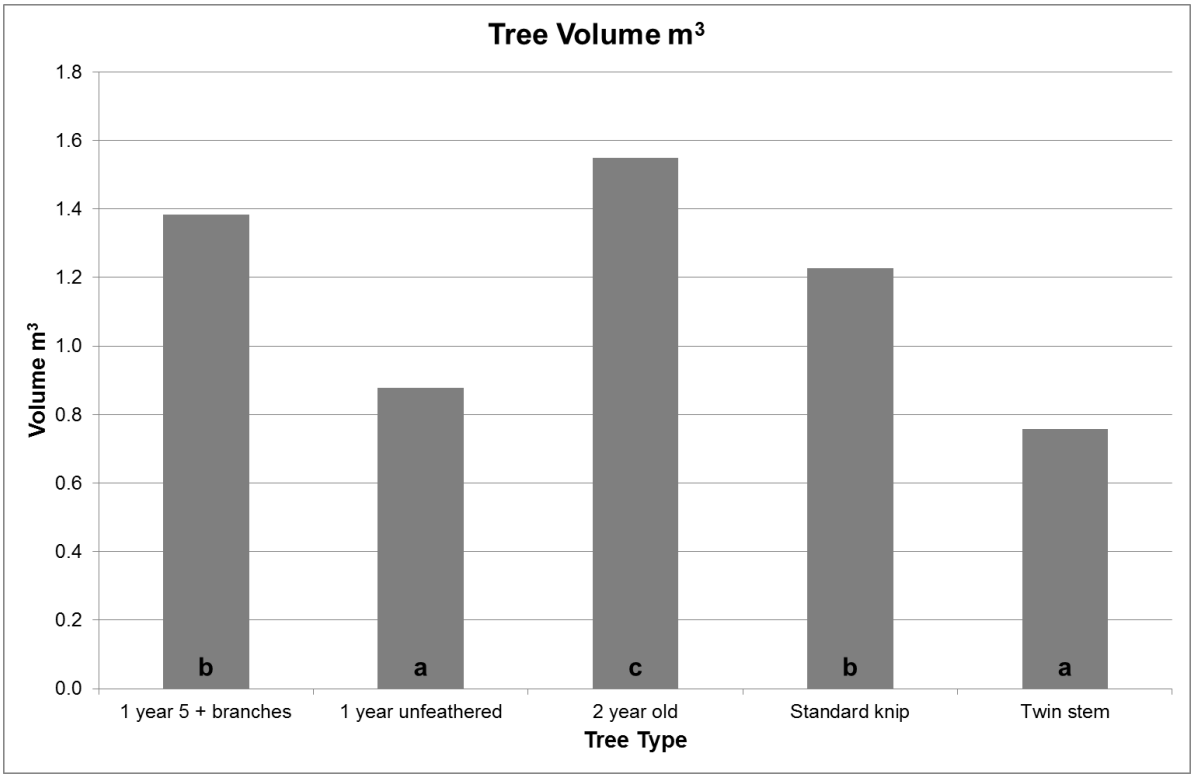

Figure 13. Tree Volume (m^3). Results with different letters are significantly different from one another (P = <0.0001).

Discussion

Yields between tree types during 2015 were still variable. This is to be expected with trees of different ages and growing methods in the nursery. It is not surprising that the 1 Year Unfeathered trees remain the lowest yielding treatment per stem because of their lack of fruiting wood. There were statistically significantly differences for all yield assessments in 2015 but compared to 2014 numerical differences between some treatments were smaller (e.g. cumulative yield where the difference between the highest and lowest yielding tree type in 2015 was 11kg but in 2014 was 14kg)

Average fruit weight in 2015 was approximately 20g less than 2014. As trees develop, numerical differences in average fruit weight between tree type is decreasing. However, Twin Stem trees had significantly heavier fruit than all other treatments apart from 1 Year Unfeathered. This may be due to these tree types' lower yields and continuing open tree structure in 2015 compared to other types.

The maturing trees are beginning to fill their space with more cropping wood, produce more fruit and are developing full crop loads. However, % fruit under 60mm was quite high – 5% to 15%. 2015 was a very heavy cropping year – in future years it will be important to manage potential yield to achieve balanced crop loads.

Overall quality in 2015 was good. Class 1 fruit percentages were low at around 70% due to a higher percentage of small Class 2 fruit (average 24%). Increases in fruit size can be made by performing quality thinning. Waste percentages were much lower in 2015 (7%) compared to 2014 (50%). Most waste fruit was due to russet – management in future can be assisted by avoiding high risk applications at blossom time.

All tree types increased in height and spread between 2014 and 2015 and tree volume doubled for all tree types. Tree heights for the less mature 1 Year Unfeathered and Twin Stems remain significantly less because of their structure and treatment in nursery. Significant differences in tree spread and volume between tree types is unsurprising e.g. Twin Stems and 1 Year Unfeathered have yet to develop substantial cropping wood.

Conclusions

- The speed at which newly planted trees can fill their space and achieve good yields in the early years after planting are crucial to the success of new orchards. Significant differences in both these measures were again noted during 2015 but actual differences in, for example, yield and volume between tree types are starting to diminish.
- It is not clear whether the responses are due to establishment of the different tree types or the pruning effects.
- Despite the results and differences determined in 2015 it is not yet conclusive which tree type is most suited to growing in a Fruit Wall system.

Knowledge and Technology Transfer

Results from 2015 have been presented at the:

- FAST LLP growers' conference on 4 February 2016 (Ivan Velasco, Advisor).
- AHDB Tree Fruit Day for Agronomists on 23 February 2016 (Abi Dalton, Trials Manager).

An article for the AHDB news was submitted in January 2016 for publication.

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Appendix 1 - photographs

Photograph series 1. 1 year 5 + Branches – plots before and after 9 leaf cut and at harvest.

Photograph series 2. 1 Year Unfeathered – plots before and after 9 leaf cut and at harvest.

Photograph series 3. 2 Year Old – plots before and after 9 leaf cut and at harvest on 8 October.

Photograph series 4. Standard Knip – plots before and after 9 leaf cut and at harvest.

Photograph series 5. Twin Stem – plots before and after 9 leaf cut and at harvest.