Project Number:	TF 206
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The results and conclusions in this report are based on an investigation conducted over a six-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.

Abi Dalton

Trials Manager

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

- Based on this six year trial of five different apple Gala tree planting types, Two-Year-Old, Standard Knip and One-Year Five-plus-Branches tree types would be more profitable than One-Year Unfeathered and Twin Stem for growing in a Fruit Wall system

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 eight month tree at a close planting distance can give better results. This project has provided 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 3.5 m by 0.8 m (density of 3571 trees/ha) except Twin Stem at 3.5 m by 1.6 m.

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. One-Year Five-plus-Branches
2. One-Year Unfeathered
3. Two-Year-Old (grow through)
4. Standard Knip
5. Twin Stem

The trial area consists of a randomized complete block with each of the five growing systems replicated in six blocks (rows) (Table 1).

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 one plot of 10 trees of each tree type (except for Twin Stems which have five trees, but two stems each), making 270 trees (300 stems) in total, on an area approximately 0.09 ha. The middle 8 trees (three trees for Twin Stems) were used for recording and sampling and the end two trees in each plot were guards (Tables 2 and 3).

Table 2. Plot layout of each row for all tree-types except Twin Stems

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

Table 3. Plot layout for rows of Twin Stem trees

	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 and shoot growth was assessed, to establish when to prune at the nine leaf stage. Photographs of trees before and after cuts are included in Appendix 1 at the end of the Science Section of this report.

Key results in 2016

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

- There were statistically significant results in yields per hectare – Two-Year-Old tree types yielded the most fruit and One-Year Unfeathered yielded the least fruit
- Fruit quality in 2016 was good – all tree types achieved over 80% Class 1 except One-Year Five-plus-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 Two-Year-Old trees continued to have the highest volume

Key results in 2017

2017 was the fourth and penultimate fruiting year.

- There were statistically significant results in yields per hectare – Two-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 – One-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 (76.4%)
- Average fruit weight was acceptable in 2017 with all tree types having average single fruit weights of >120g except Two-Year-Old (116.5 g). One-Year Five-plus-Branches had the heaviest average fruit weight of 131.4 g
- Percentage fruit size was acceptable with all tree types having 60% fruit between 60 mm and 70 mm and <10% fruit under 60 mm
- Tree volume decreased for all tree types in 2017 compared to 2016. The Two-Year-Old trees continue to have the highest volume

Key results in 2018

- There were statistically significant effects of tree type on yield per hectare in 2018 - Standard Knip trees had higher Class 1 yields than other tree types
- Twin Stem had the lowest Class 1 yields, which were statistically not different to One-Year Unfeathered
- Two-Year-Old trees had the highest cumulative yields per hectare and Twin Stem and One-Year Unfeathered the lowest
- Twin Stem had the highest yield efficiency of all tree types and Two-Year-Old the lowest
- Fruit quality in 2018 appeared unaffected by climatic conditions and was commercially acceptable at >80% Class 1. Twin Stem had the highest Class 1 fruit (84.1%) and One-Year Unfeathered the lowest (81.7%). Marketable (Class 1 and 2) fruit percentages were >90% for all tree types
- There were no significant effects of tree type on average fruit weight in 2018. Acceptable average single fruit weights of >120g were achieved for all tree types except One-Year Five-plus-Branches, which had the lowest (118.5 g), whereas in 2017 it had the highest. Twin Stem had the highest average fruit weight of 127.5 g

- Percentage fruit size in 2018 was acceptable with all tree types having >60% fruit sized between 60 mm and 70 mm. There were low percentages of small fruit (<60mm) and very low percentages of fruit >75mm
- All tree types increased in volume in 2018 or were static except for Twin Stem which decreased. The Two-Year-Old trees continue to have the highest volume

Main conclusions from the trial

Statistically significant differences in yields were due initially to tree type, but latterly responses have diminished as trees matured and fruiting wood increased.

The Fruit Wall cut was carried out when nine new leaves had emerged in the 2018 season's growth. To determine this, growers regularly need to make random leaf counts to establish the growth stage before carrying out mechanical pruning.

Pruning was delayed in some years of the trial and growers may be faced with a similar logistical problem in commercial practice. Sub optimal pruning (timing and quantity) could negatively affect bud initiation and careful consideration of when and where to make the Fruit Wall cut is required. Growers must robustly monitor crop growth stage and assess bud formation. They should not cut at exactly the same point each year.

A different assessment of tree volume such as Leaf Wall Area or Porosity may be a more accurate method for estimating and revealing differences between tree types in the development of fruit bud/cropping wood.

An assessment of fruit set, bud number and quality can help thinning and crop load management decisions.

Minimal inter tree pruning was carried out on the trial trees for the second time in spring 2018. Requirements must be considered and trees will need pruning regularly once commercial orchards reach maturity. Only one or two cuts per tree per season should be required.

Fruit size in irrigated orchards will be easier to maintain. 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 orchard areas.

Fruit Wall managed trees have a narrow profile and may be suited to growing in narrower alleyways (2.5 m) rather than 3.5 m used 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 6,667 if trees were planted within row at 0.6 m and to maximise the yield efficiency of orchards managed under the Fruit Wall system.

Based on early yields in this trial compared with predicted returns and considering tree costs, Two-Year-Old, Standard Knip and One-Year Five-plus-Branches would be more profitable than One-Year Unfeathered and Twin Stem for growing in a Fruit Wall system at the same tree height and alley width as in the trial.

However, whilst Twin Stem and One-Year Unfeathered trees in this trial had statistically lower volumes and yields than the other tree types, were slower to establish and had higher incidences of disease, their higher yield efficiency suggests that they could be grown at reduced inter-row and alley widths and lower canopy height without yield reductions.

Mechanical pruning could be used to convert existing orchards or as part of a husbandry management programme. Mechanically pruned orchard systems grown with a significantly further reduced profile and reduced alley width could be beneficial with the introduction of mechanised harvesting.

Financial Benefits

- The trial has attempted to support industry requirements of shortening payback periods and to produce guidance on the cropping potential of different tree types in the early years
- The trees have carried five crops, four of which have been heavy. Tree types yielded commercially acceptable marketable quantities in 2017, but not in 2018
- Based on results from this trial, there would be minimal value to the grower until the fourth or fifth fruiting year of a similarly established new Fruit Wall managed orchard
- Increased long term returns are unlikely based on results from this trial and predicted potential yield increases from the best tree type for Fruit Wall systems may be unrealistic
- However, yield responses in more vigorous orchards may be different and should be higher than the trial orchard
- Twin Stems or One-Year Unfeathered may be viable profitable options given their enhanced yield efficiency and if planted at higher densities (despite increased tree and planting costs for Twin Stems and assuming they will be disease free) (e.g. 6,667 trees/ha – 0.6 m planting distance within row and a reduced row width of 2.5

m plus low canopy height <2.0m). This type of management could assist growers with the development of mechanical picking

- Alternatively, growers should be able to reduce pruning costs from the reduced labour input required if mechanical pruning is used as part of an orchard management programme

The cost of successfully establishing an intensive orchard is approximately £32,000 per hectare (depending on price variation of materials and exchange rates) (FAST 2019). In particular:

a. The differences in costs of the various tree types available vary depending on type selected and quantity (up to an extra £3.02 per tree or from an extra £174 to £3465 per hectare (FAST 2019)). Some tree types (e.g. Two-Year-Old) have the potential to increase in volume much more quickly. However, this would be unnecessary if planting at narrow alley widths and maintaining a reduced canopy spread. Therefore, considering the least expensive tree (e.g. One-Year Unfeathered / Whip) for Fruit Wall management may be beneficial.
b. An estimated reduction in yield from a Fruit Wall system of 5% in each of the first five cropping years can reduce net returns by around £3000 per ha (FAST 2018). However, the real percentage reduction for all tree types in the first five cropping years of this Fruit Wall trial has been much greater. The One-Year Unfeathered trees had the highest percentage reduction from 2014 to 2016 (87.1%, 32.6% and 48.5%) and Twin Stem the highest in 2017 and 2018 (19.1% and 34.9%). However, some of this reduction is likely to have been caused by diseases (like scab and canker) in these tree types. Only One-Year Five-plus-Branches, Two-Year-Old and Standard Knip had equal to or less than 5% percentage reductions in 2015 and 2017 (Table 1). Based on cumulative marketable yields the overall reduction for the duration of the trial still falls below the estimated reduction of 5% (between -14.1% for Two-Year-Old and -36.4% for Twin Stem) (Table 2). Some differences could be attributable to the tree types, orchard and climate conditions. Results from AHDB TF 207 (Determination of the optimum pruning time for fruit wall orchard systems for Gala apple) also demonstrated lower yields in mechanically pruned trees than from hand pruned treatments.
c. 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 (SCRIPPS 2017). Hand pruning speed is improved if

electronic secateurs are used, but these cost around £1500 each. Younger trees such as those in this trial would take less time to hand prune, e.g. three days. Some hand pruning will be needed (e.g. inter pruning) even where mechanical pruning is used, but net savings of around £6,300/ha over a 15 year orchard life are envisaged (excluding machinery costs).

Table 1. Percentage difference of yearly Fruit Wall marketable yields (Class 1 and 2) compared to commercial expected yields for five years, from 2014 to 2018 (25, 35, 45, 45 & 50 t/ha respectively) – shaded cells indicate similar to or greater than estimated Fruit Wall reduction of 5%

TREE TYPE / YEAR	2014	2015	2016	2017	2018
1 Year 5 + Branches (maiden)	-75.0	-4.4	-30.3	12.5	-10.1
1 Year Unfeathered (whip)	-87.1	-32.6	-48.5	-10.2	-23.1
2 Year Old	-67.9	0.5	-21.4	11.1	-13.5
Standard Knip	-77.5	-5.3	-25.1	5.8	-9.1
Twin Stem	-82.4	-21.4	-41.6	-19.1	-34.9

Table 2. Percentage difference of cumulative Fruit Wall marketable yields (Class 1 and 2) compared to commercial expected cumulative yields for five years, from 2014 to 2018 (25, 60, 105, 150 & 200 t/ha respectively)

TREE TYPE / YEAR	2014	2015	2016	2017	2018
1 Year 5 + Branches (maiden)	-75.0	-33.8	-32.3	-18.9	-16.7
1 Year Unfeathered (whip)	-87.1	-55.3	-52.4	-39.7	-35.6
2 Year Old	-67.9	-28.0	-25.2	-14.3	-14.1
Standard Knip	-77.5	-35.4	-31.0	-19.9	-17.2
Twin Stem	-82.4	-46.8	-44.6	-36.9	-36.4

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 One-Year Five-plus-Branches, Two-Year-Old and Standard Knip achieved marketable t/ha of 50.6, 50.0 and 47.6 respectively (Table 3). This equals up to between 12.5%, 11.0% and 5.8% yield increases compared to commercial standard trees of the same age (Table 1). However, this yield increase

was not seen in 2018 when only Standard Knip trees yielded above the estimated percentage reduction of 5% (48.4 t/ha) and no tree type yielded above standard commercial expectations of 50 t/ha.

Table 3. Marketable yields (Class 1 and 2) 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	2018
1 Year 5 + Branches (maiden)	6.2	33.5	31.4	50.6	45.0
1 Year Unfeathered (whip)	3.2	23.6	23.2	40.4	38.4
2 Year Old	8.0	35.2	35.4	50.0	43.2
Standard Knip	5.6	33.1	33.7	47.6	45.5
Twin Stem	4.4	27.5	26.3	36.4	32.5
Standard commercial	25.0	35.0	45.0	45.0	50.0
Standard commercial - 5%	23.8	33.3	42.8	42.8	47.5

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 £18,500 per machine (Seymour 2017), but this could also be used for other operations on the farm e.g. hedge and windbreak cutting and could also be rented out.

f. 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 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.

g. Continued adaptation of this trial's developmental work would be beneficial including investigating the best yield efficiency tree types at even higher density plantings (e.g. 0.6 m x 2.5 m, creating 6,667 trees per hectare). This work could contribute to the current trend for creating orchards ready to utilise mechanical harvesters.

Action points for growers

- The Fruit Wall cut was carried out when 9 new leaves had emerged on the current season's growth. To determine this, growers regularly need to make random leaf counts to establish the growth stage before carrying out mechanical pruning
- Growers must robustly monitor crop growth stage and assess bud formation. They should not cut at exactly the same point each year
- An assessment of fruit set, bud number and quality can help thinning and crop load management decisions
- Requirements must be considered and trees will need pruning regularly once commercial orchards reach maturity. Only one or two cuts per tree per season should be required
- 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 orchard areas

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. Mechanised harvesters and semi-automated in orchard harvesting equipment continue to be developed (FAST 2019). 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 mechanisation of pruning is now being undertaken commercially in the UK, but Fruit Wall systems 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 managed 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 due to lack of red colour (despite growers, in practice, planting more red coloured Gala clones). However, 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 any Fruit Wall orchard 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 40 cm wide at the top and 80 cm 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 bud 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 regrowth 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, 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 was 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 and completed in 2018.

Gala trees (clone Royal Beaut) were sourced from specialist nurseries. All of the trees were supplied by nurseries in the Netherlands except for the Twin Stem trees, which came from patented 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.

The trees were planted in March 2013 at Brogdale Farm, Brogdale Road, Faversham, Kent, ME13 8XZ (Stumble field, FAST LLP, latitude 51.290020, longitude 0.87840289).

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

The trees were planted at a distance of 3.5 m by 0.8 m (density of 3571 trees/ha) except Twin Stem at 3.5 m by 1.6 m (density of 1786 trees/ha).

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

The trees were not irrigated during establishment or during the trial.

The trees were grown according to Good Agricultural Practice following IPM protocols. Husbandry was carried out to commercial standards. During and since establishment, regular crop monitoring was carried out by a BASIS qualified FAST advisor for pest and disease. Standard commercial spray programmes were applied as necessary or if thresholds were exceeded and according to IPM Best Practice. A standard commercial nutrition programme was followed as recommended by FAST FACTS qualified advisors and based on previous soil samples.

The five different tree types selected were:

1. One-Year Five-plus-Branches (maiden)
2. One-Year Unfeathered (whip)
3. Two-Year-Old (grow through)
4. Standard Knip
5. Twin Stem

The trial area consisted of a Randomized Complete Block with each of the five tree types replicated in six rows (blocks):

Table 4. Trial plan

Twin Stem	2 Year Old	1 Year 5 + Branches	1 Year Unfeathered	Standard Knip	1 Year Unfeathered
2 Year Old	1 Year 5 + Branches	Standard Knip	2 Year Old	1 Year Unfeathered	Twin Stem
1 Year Unfeathered	Twin Stem	2 Year Old	Standard Knip	1 Year 5 + Branches	Standard Knip
1 Year 5 + Branches	Standard Knip	1 Year Unfeathered	Twin Stem	2 Year Old	1 Year 5 + Branches
Standard Knip	1 Year Unfeathered	Twin Stem	1 Year 5 + Branches	Twin Stem	2 Year Old
Block 1	**Block 2**	**Block 3**	**Block 4**	**Block 5**	**Block 6**

Each row had one plot of 10 trees of each tree type (except for twin stems which had five trees but 10 stems), making 270 trees (300 stems) in total, on an area approximately 0.09 ha. The middle eight trees (three trees for twin stems) were used for recording and sampling and the end two trees in each plot were guards (Tables 5 and 6).

Table 5. Plot layout for rows of all tree types except Twin Stems

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

Table 6. Plot layout for rows of Twin Stems trees

	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 spring of 2018, trees were minimally inter pruned (two 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 infections were again noticed in the trial plot. Any diseased material was removed. Disease presence was again most prevalent in the Twin Stem trees.

Other disease pressure within the orchard was moderate for Scab (*Venturia inaequalis*) and low for Powdery Mildew (*Podosphaera leucotricha*).

There were extreme weather events during 2018 including a severe and enduring cold period in February 2018 where day time temperatures at Brogdale reached -8ºC and night time temperatures -14ºC. Below zero temperatures were maintained for many hours and days. There were no frosts during flowering or early fruitlet, but it was very windy at times during flowering. There were low night time temperatures (2ºC to 8ºC) in April and May during flowering and some above average day time temperatures (>20ºC but fluctuating with maximums of between 7ºC and 15ºC). Rainfall from January to May was above average and there were several periods of very heavy rain including in May and August. Day and night time temperatures in June, July and August were above average and maximum day time temperatures exceeded 30ºC on many consecutive days. Total rainfall during this later period was well below average.

Growth stages were monitored regularly during April 2018 and shoot growth assessments commenced in mid-May in order to establish when to prune at the nine leaf stage which occurred on 13 June (1 week later than 2017).

Following the Fruit Wall cut, all trees were thinned between 11 and 13 July to two fruit per cluster on branches below 1.5 m and one fruit per cluster on branches above 1.5 m.

Fruit was harvested on 25 September following maturity testing to determine the optimum harvest date, placed into cold store and assessed later for quality and size.

Assessments

Counts of leaves on new extension growth were undertaken in order to determine the correct date to carry out the Fruit Wall cut at the nine leaf stage. One shoot on both sides of each tree or stem was assessed (20 shoots per plot). The Fruit Wall cut was then made after the shoot extension growth had reached a mean of nine fully expanded leaves. The branches were cut back by hand (simulating a mechanical cut) to a maximum length of 40 cm each side at the base of the tree and 20 cm at the apex (giving a total width per tree of 80 cm and 40 cm respectively).

Harvest date was predicted using results from the FAST advisory testing service and maturity testing (a visual percentage score of starch stained black by iodine on the surface of halved apples taken from the trial's guard trees). The total yield (kg) was recorded from each treatment plot at harvest. The average yield per tree and average yield per stem were calculated.

A random sample of 100 fruits from each plot was collected prior to harvest – six or seven fruits from each side of the eight assessment trees from various parts of the canopy (high 2.0 m, middle 1.5 m and low 1.0 m). Fruit was placed in cold storage and assessed during the autumn for quality (Class 1, Class 2 and Waste), weight and size.

Percentages of fruit within each class category (weight g) were calculated.

The average fruit weight (g) was calculated.

The percentage of total yield within each of six size categories was calculated.

Height was measured using a decimetre placed on the ground and held by one operative. The second operative viewed the rule from the same distance and angle for each tree recording the height of the tallest growing point. Two spread measurements were taken diagonally within the tree canopy using upright canes to mark the outermost branches and the distance between them recorded. Tree volume was calculated. Each Twin Stem tree was treated as two trees and the height and spread for each stem was measured separately (making six in total rather than eight as for the other tree types).

Yield efficiency was calculated as an estimation of the tree productivity per canopy area - in this trial by dividing yield (t/ha) by volume (m^3).

Statistical Analysis

Where appropriate, statistical analysis was carried out on single independent variables (tree types) using one-way Analysis of Variance (ANOVA) (including any data transformations where scores or percentages were used). Where effects of treatments were statistically significant (P value <0.05) further analysis of the means was carried out via Multiple Range Tests (MRTs) using Fishers Least Significant Difference (LSD) procedure to determine which treatments were significantly different from one another (at the 95% confidence level). With this method there is a 5% risk of calling pairs of means significantly different when the actual difference equals zero (e.g. average yield of tree type 1 versus tree type 2). Results of the MRTs are detailed on the tables and charts as letters. Where applicable, charts are also shown with standard error bars (a graphical representation of the variability of the data and how precise a measurement is). Large standard errors indicate that data were more

variable from the mean and the mean may be a less reliable representation of the data (although no less valid).

A statistically significant difference means that results seen are most likely due to the treatment effects on the plant population rather than to chance or sampling error. In summary, where statistically significant differences between treatments were found and if a trial were repeated, it is likely that results would be the same 95 times out of 100 i.e. the initial results were not caused by chance alone. Where it is not possible to analyse data (e.g. where raw data is not gathered, rather calculated from means of other) it is not possible to say whether the results were caused by chance alone and therefore, if trials were repeated, whether results would be duplicated. Different results are likely to occur if trials were repeated. This is important where numerical differences appear substantial and there were no statistical differences or data was not analysed. Where there is correlation this does not necessarily mean causation.

Results

Leaf counts

Leaf development monitoring started in May 2018 and detailed leaf counts commenced on 21 May. The average number of fully expanded leaves on new shoot growth was calculated on 3 assessment dates and is shown in Table 7.

Table 7. Leaf counts for 2018 – average number of fully expanded leaves

Date / Type 2018	1 Year 5 +	1 Year Unfeathered	2 Year Old	Standard Knip	Twin Stem	Overall
21 May	4.7	4.4	4.4	4.3	4.4	4.4
30 May	7.7	7.4	7.1	6.7	7.0	7.2
5 June	8.6	8.3	9.2	8.3	8.0	8.5

The Fruit Wall pruning was carried out on 13 June 2018.

Yield

Yield data was recorded at the harvest conducted on 25 September 2018. Averages and Class 1 tonnes per hectare are displayed below in Tables 8 and 9.

Table 8. Total yield for 2018, average yield per tree and per stem (kg) for five different tree types

Tree Type / Yield (kg)	Total Yield (kg)	Average Yield per Tree (kg)	Average Yield per Stem (kg)
1 Year 5 + Branches	583.5 b	13.3 a	13.3 bc
1 Year Unfeathered	496.3 b	11.3 a	11.3 ab
2 Year Old	578.7 b	12.9 a	12.9 bc
Standard Knip	568.9 b	13.5 a	13.5 c
Twin Stem	315.6 a	19.7 b	9.9 a

Table 9. Class 1 yield per hectare (t/ha) over five years for five different tree types

Tree type / Year	2014	2015	2016	2017	2018
1 Year 5 + Branches	14.0	35.9	35.0	53.3	39.4
1 Year Unfeathered	5.3	26.1	25.7	42.3	33.4
2 Year Old	19.0	37.4	38.5	54.1	38.7
Standard Knip	11.9	36.1	35.8	50.4	40.6
Twin Stem	8.1	29.0	28.4	39.5	29.9

Total yields for all plots for each tree type in 2018 was between 315.6 kg (Twin Stem) and 583.5 kg (Two-Year-Old). Twin Stem had significantly lower yields than all other treatments (Table 8 and Figure 1).

However, Twin Stems had significantly higher yields per tree than any other type (19.7 kg) (since they have two stems instead of one). The lowest average yield per tree was 11.3 kg for One-Year Unfeathered trees. All average yields per tree decreased in 2018 compared to 2017 (Table 8 and Figure 2).

There were significant effects of tree type on yield per stem in 2018 where Standard Knip trees had higher yields than any other (13.5 kg). The lowest yield per stem was for Twin Stem (9.9 kg) and which was significantly lower than all other tree types except One-Year Unfeathered. Yield per stem results for One-Year Five-plus-Branches, One-Year Unfeathered and Two-Year-Old were statistically similar (Table 8 and Figure 3).

There were significant effects of tree type on yield Class 1 tonnes per hectare where Twin Stem had significantly lower yields (29.9 t/ha) than all other tree types except One-Year Unfeathered (33.4 t/ha). Standard Knip had the highest yields of 40.6 t/ha, but this result was not statistically different to One-Year Five-plus-Branches (39.4 t/ha) and Two-Year-Old (38.7 t/ha) (Table 9 and Figure 4).

The final cumulative profile shows that Two-Year-Old trees have yielded more fruit than any other tree type (±195 t/ha). One-Year Five-plus-Branches and Standard Knip have numerically similar totals (Figure 5).

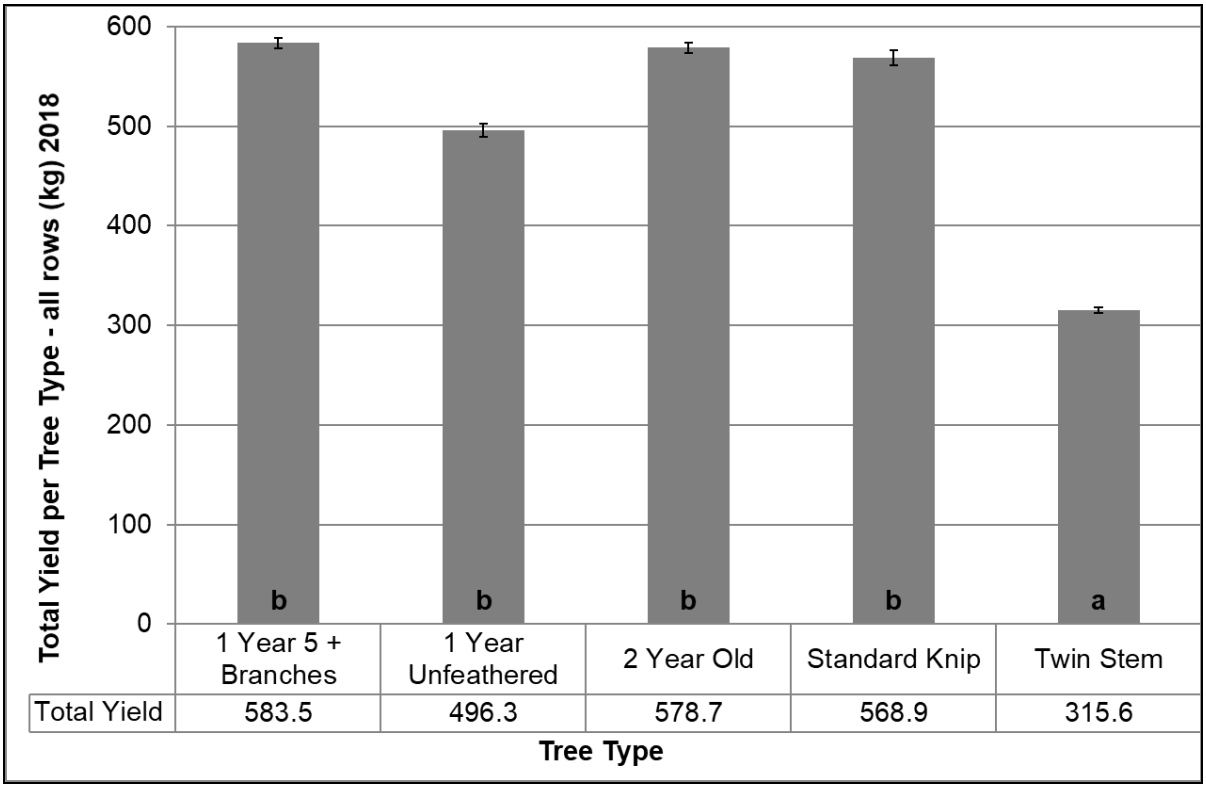


Figure 1. Total Yield per Tree Type (kg) in 2018. Results with different letters are significantly different from one another (p value = <0.001)

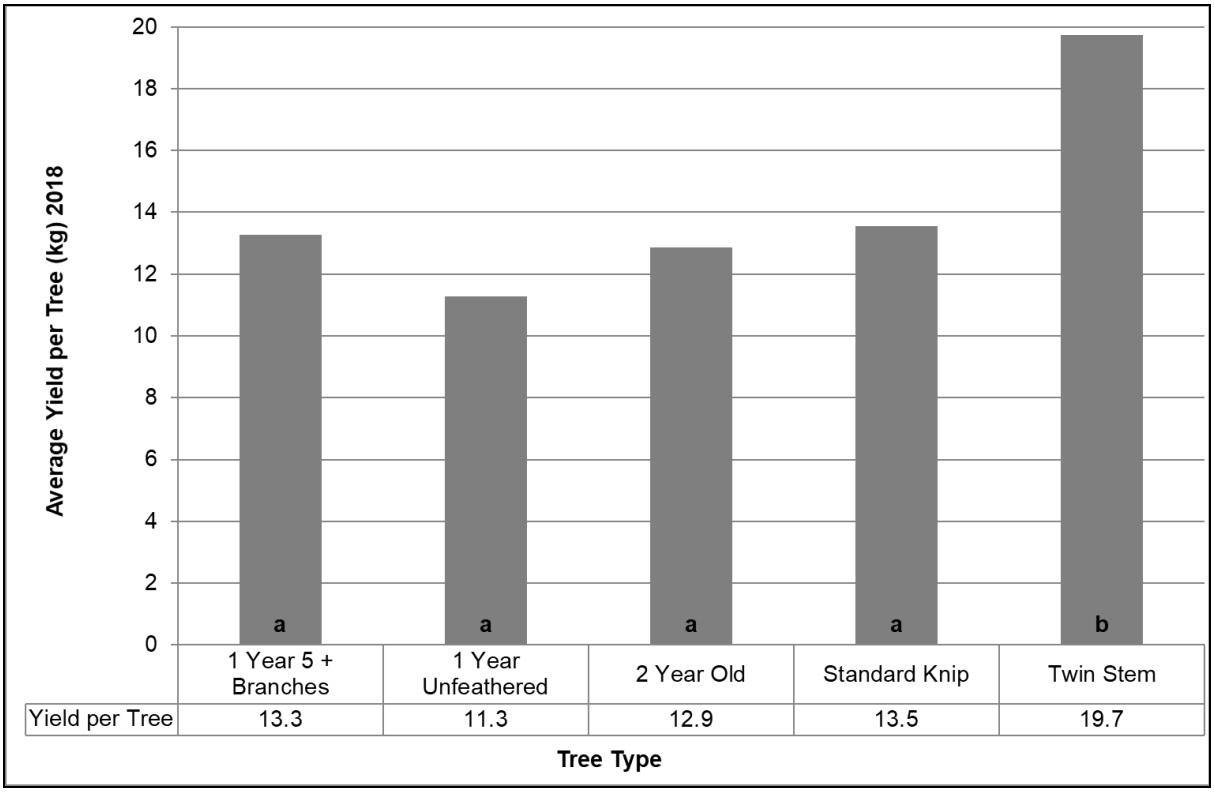


Figure 2. Average Yield per Tree (kg) in 2018. Results with different letters are significantly different from one another (p value = <0.0063)

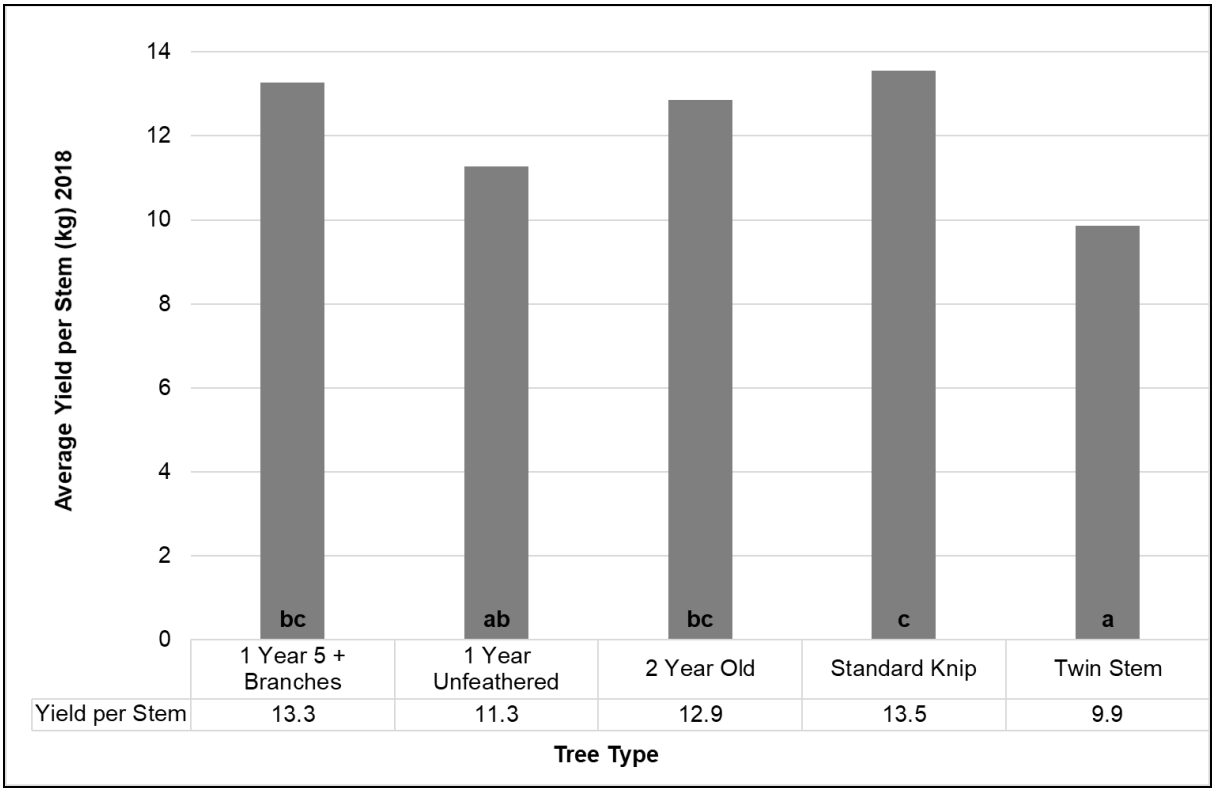


Figure 3. Average Yield per Stem (kg) in 2018. Results with different letters are significantly different from one another (p value = 0.0071)

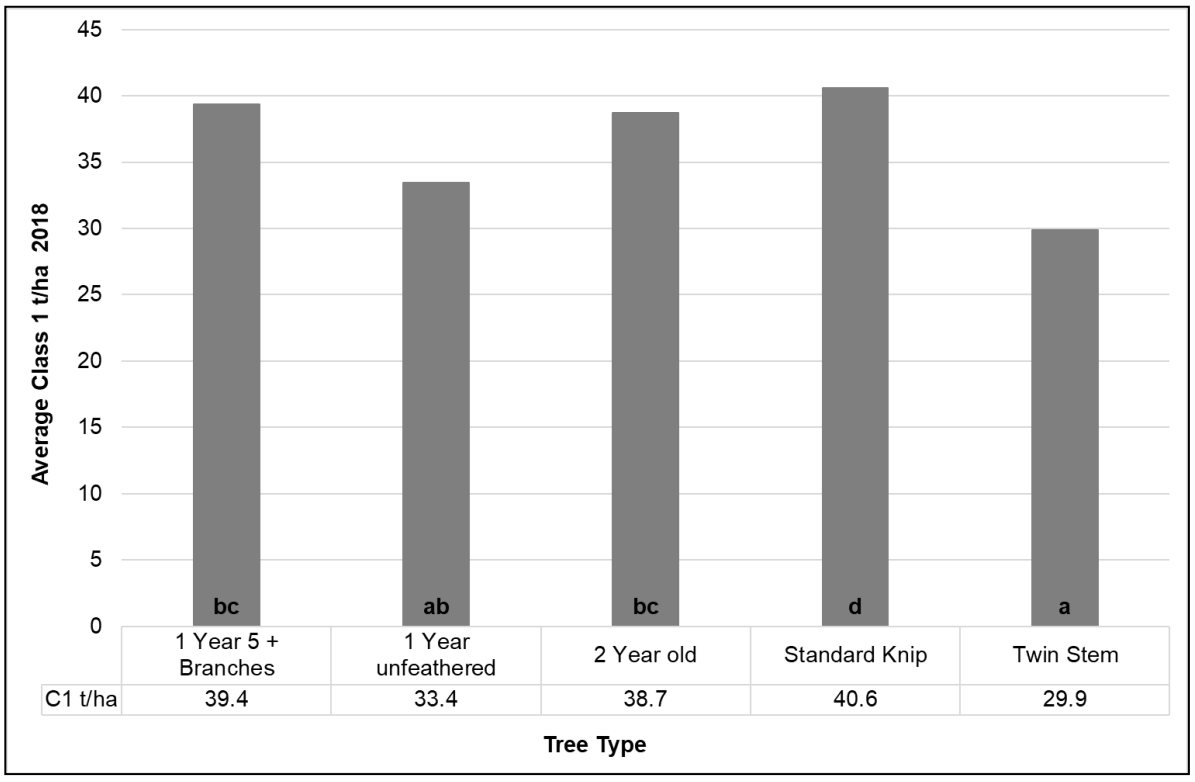


Figure 4. Average Class 1 t/ha in 2018. Results with different letters are significantly different from one another (p value = 0.0229)

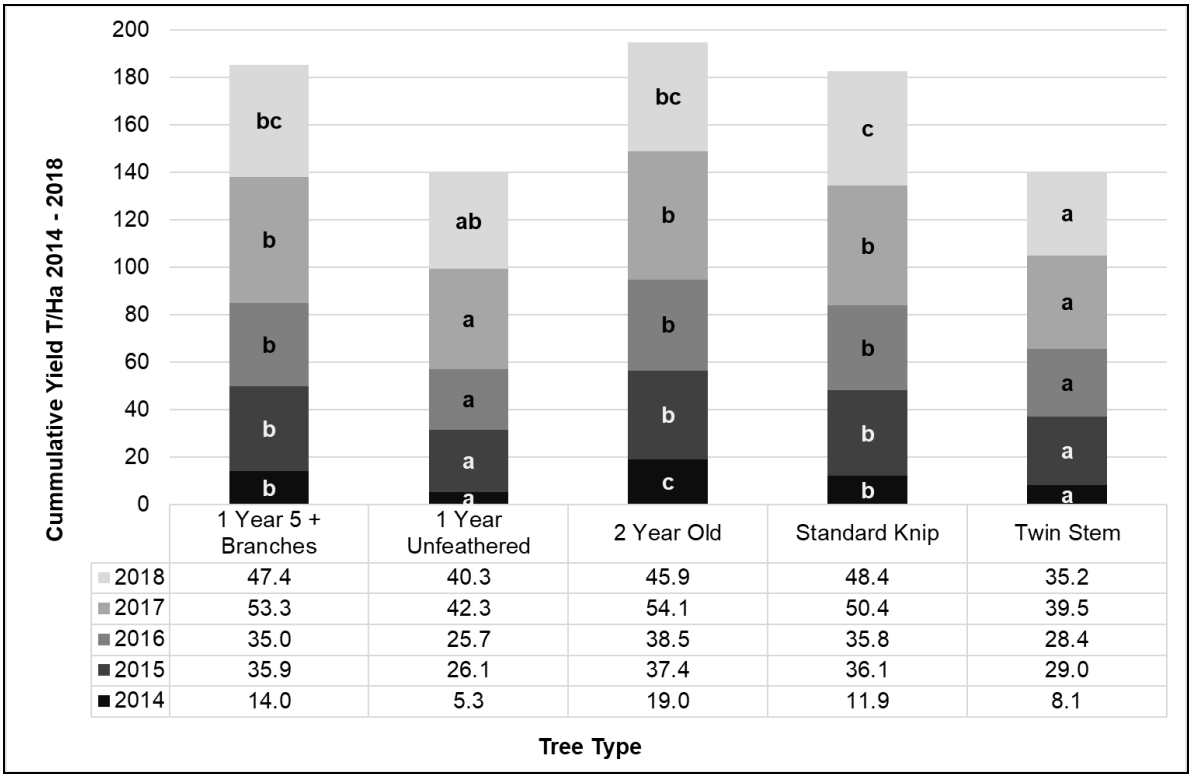


Figure 5. Cumulative Yield tonnes per hectare 2014 to 2018 (total all classes) for five tree types. Results with different letters are significantly different from one another (2018, lightest grey, p value = 0.0071)

Quality (class)

Quality assessments were made after harvest during the autumn of 2018.

Table 10. Class 1, Class 2 & Waste in 2018 – Percentage (%) by Fruit Weight

2018 % Class/Type	1 Year 5+ branches	1 Year Unfeathered	2 Year Old	Standard Knip	Twin Stem
Class 1	83.0	81.7	84.0	83.9	84.1
Class 2	11.9	14.2	10.1	10.1	8.2
Waste	5.1	4.1	5.9	6.0	7.6

In 2018, Class 1 fruit percentage was highest for Twin Stem tree type (84.1%) and lowest for One-Year Unfeathered (81.7%). See Table 10 and Figure 5.

Class 2 fruit was highest for One-Year Unfeathered (14.2%) and lowest for Twin Stem (8.2). Most fruit was assessed as Class 2 due to russet and disease (Table 10 and Figure 5).

Percentage of Waste fruit was highest for Twin Stem (7.6%) and lowest for One-Year Unfeathered (4.1%). Most fruit was downgraded to Waste due to size, damage or disease (Table 10 and Figure 5).

Fruit weight

Average fruit weight was calculated from the 100 fruit randomly sampled from each tree type plot at harvest.

Table 11. Average Fruit Weight (g)

Tree Type / Average Fruit Weight g & Year	2014	2015	2016	2017	2018
1 year 5 + branches	132.8	107.0	96.5	131.4	118.5
1 year unfeathered	130.3	115.1	100.7	121.7	121.5
2 year old	135.1	108.7	94.5	116.5	122.8
Standard knip	128.5	111.9	103.7	123.5	125.5
Twin stem	147.7	119.8	100.0	120.9	127.1

Average fruit weight in 2018 was between 118.5g (One-Year Five-plus-Branches) and 127.1g (Twin Stem). There were no statistically significant differences in fruit weight between treatments in 2018 (Table 11 and Figure 6).

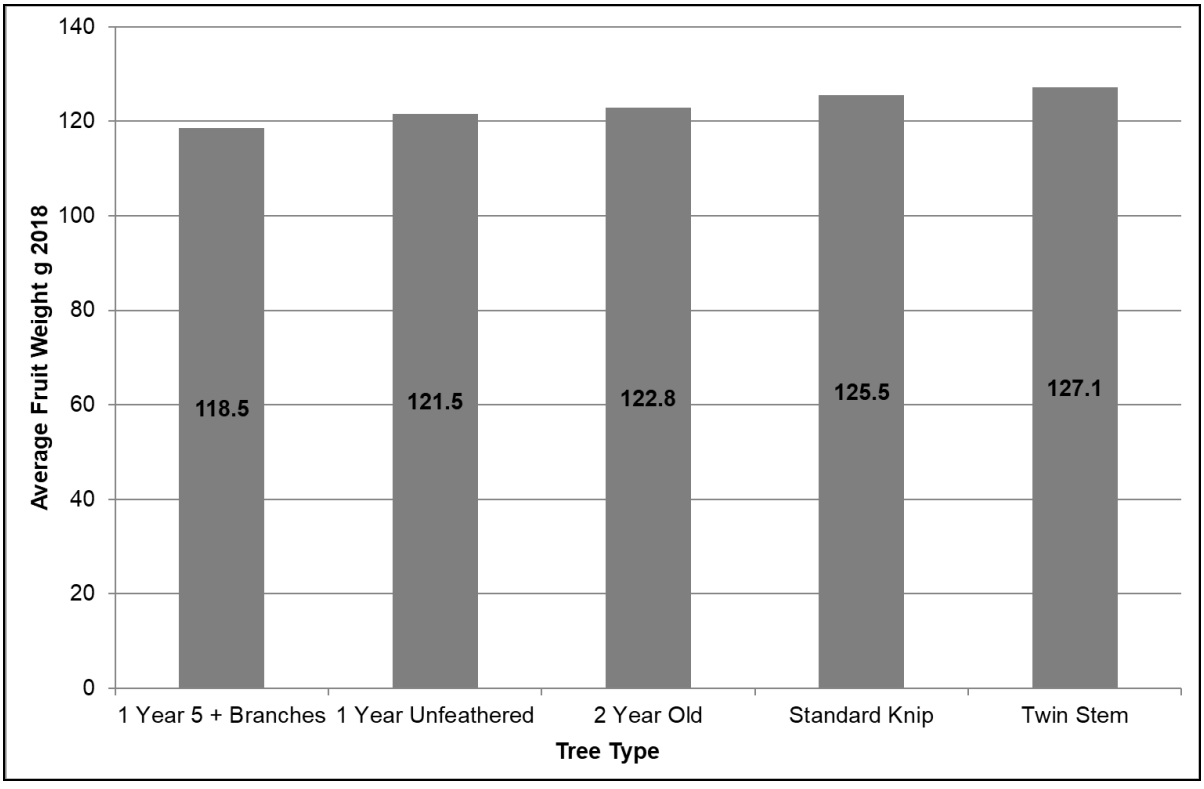


Figure 6. Average Fruit Weight (g) in 2018 for five tree types. There were no significant effects (p value = 0.0717)

Fruit size

Fruit was assessed for size after harvest during the autumn of 2018.

Table 12. Class 1 - percentage fruit by weight within size categories in 2018

2018 Fruit size / Tree type	1 Year 5+	1 Year Unfeathered	2 Year Old	Standard Knip	Twin Stem
<60 mm	10.4	11.1	9.7	9.7	7.7
60-65mm	30.5	26.4	24.5	24.2	24.4
65-70mm	42.6	41.6	41.8	36.5	42.6
70-75	15.6	18.2	21.9	26.2	21.5
>75mm	0.9	2.7	2.1	3.4	3.9

One-Year Five-plus-Branch trees had the highest combined percentage of C1 fruit sized 60 mm to 70 mm (73.1%) and Standard Knip the lowest (60.7%) (Table 12 and Figure 7). One-Year Five-plus-Branch trees had the highest percentage of fruit under 60mm (10.4%) and Twin Stem had the lowest (7.7%) (Table 12 and Figure 7).

All tree types had some fruit over 75mm in 2018 like in previous years.

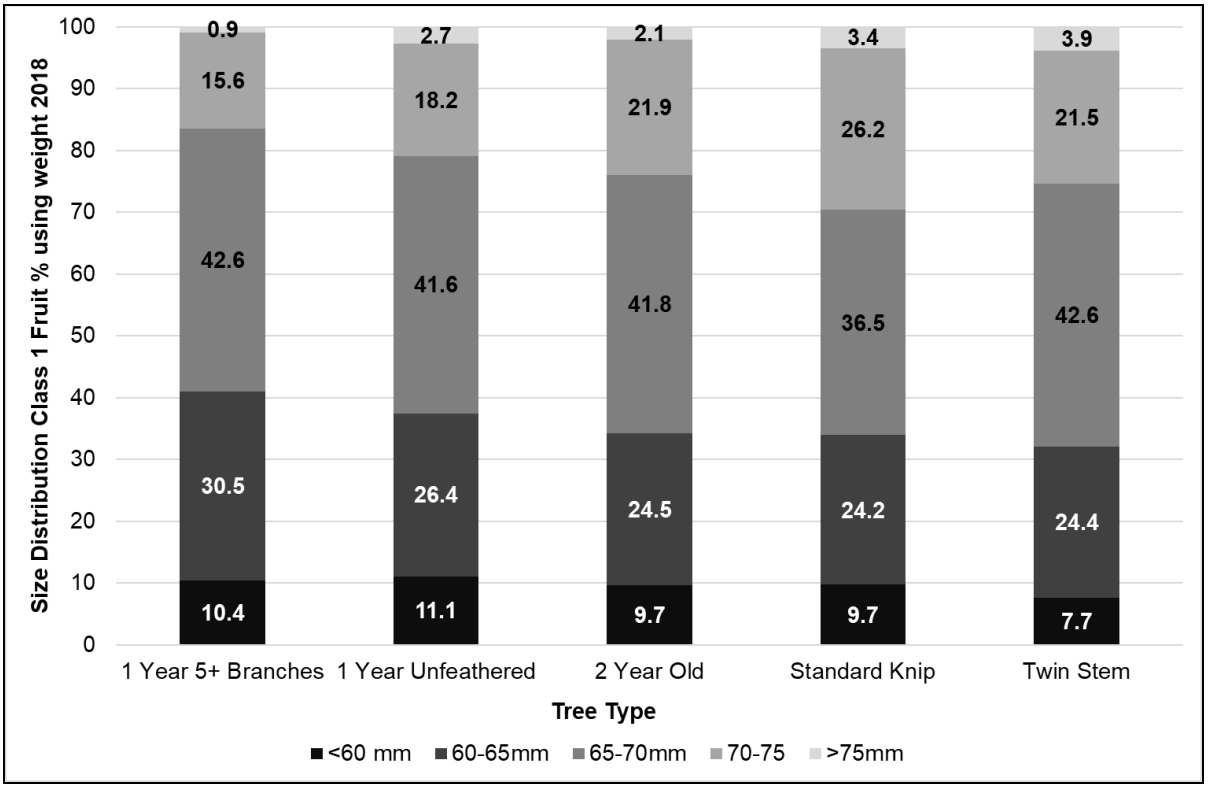


Figure 7. Percentage Size Distribution of Class 1 Fruit using weight in 2018 for five different tree types

Tree height, spread and volume

Tree height and spread were measured in November 2018 and the volume calculated.

Table 13. Tree height, spread and volume in 2018

Treatment 2018	Average Height cm	Average Spread cm	Average Volume m^3
1 Year 5 + branches	306.0 c	108.4 bc	0.94 c
1 Year Unfeathered	290.1 b	100.4 ab	0.77 b
2 Year Old	319.3 d	114.9 c	1.08 c
Standard Knip	312.2 cd	114.0 abc	0.95 c
Twin Stem	265.4 a	97.2 a	0.61 a

The average tree height varied between 319.3cm for Two-Year-Old trees and 265.4 cm for Twin Stems. Two-Year-Old trees were significantly taller than all other tree types except Standard Knip. Twin Stem trees were significantly shorter than all other treatments. Average heights increased for all tree types (Table 13 and Figure 8).

The average spread varied between 114.9 cm for Two-Year-Old trees and 97.2 cm for Twin Stem. Twin Stem and Two-Year Old trees had significantly different spreads. Spreads in 2018 decreased for One-Year Five-plus-Branches and Two-Year-Old, but increased for other tree types (Table 13 and Figure 9).

The average tree volume varied between 1.08 m^3 for Two-Year-Old trees and 0.61 m^3 for Twin Stem trees. There were significant effects of tree type on volume – One-Year Unfeathered and Twin Stem had significantly different tree volumes to each other and lower than all other tree types. Tree volume for Twin Stem decreased in 2018, but increased or remained the same for other tree types (Table 13 and Figure 10).

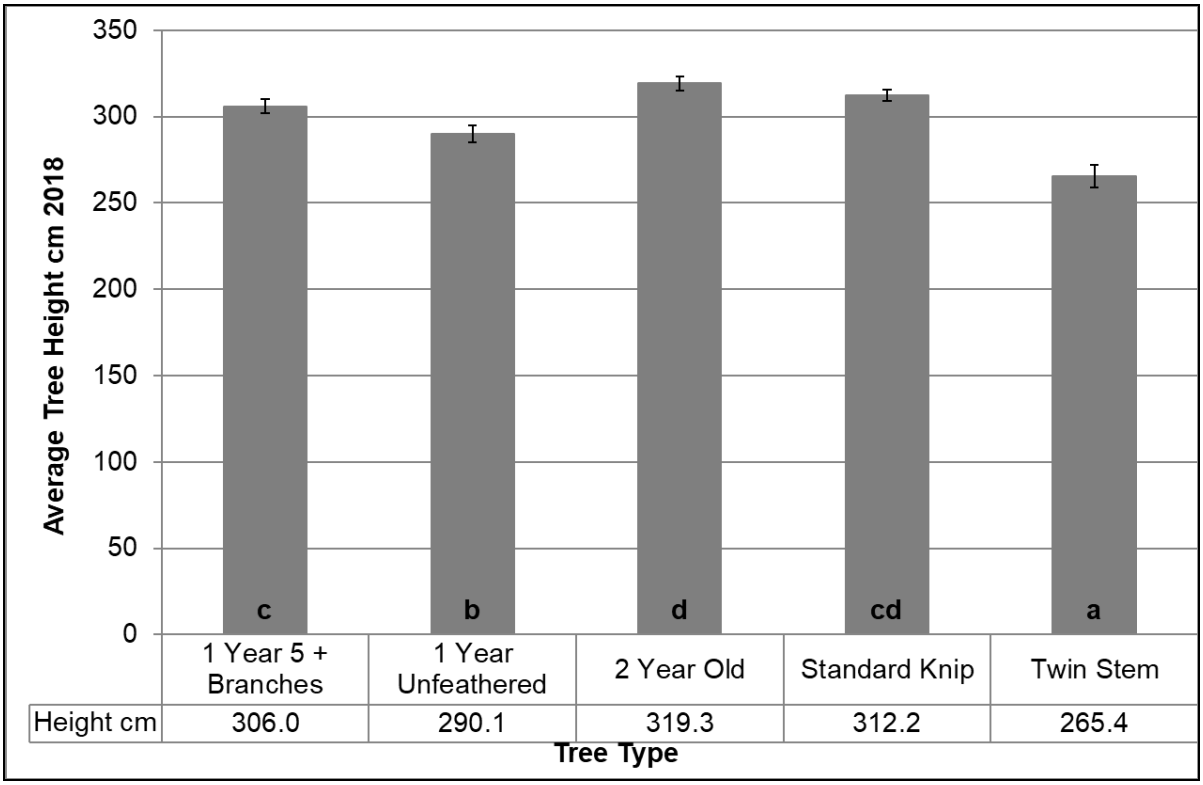


Figure 8. Tree Height (cm) in 2018 for five different tree types. Results with different letters are significantly different from one another (p value = <0.0001)

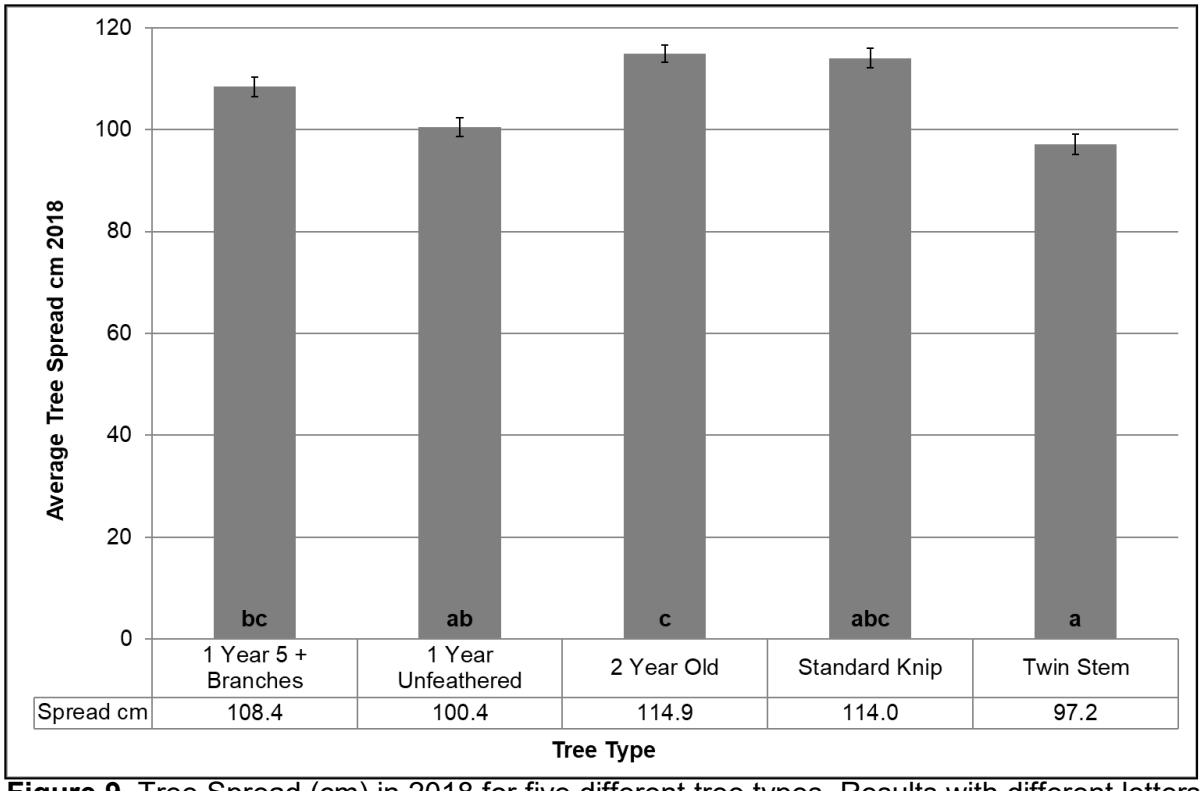


Figure 9. Tree Spread (cm) in 2018 for five different tree types. Results with different letters are significantly different from one another (p value = 0.0085)

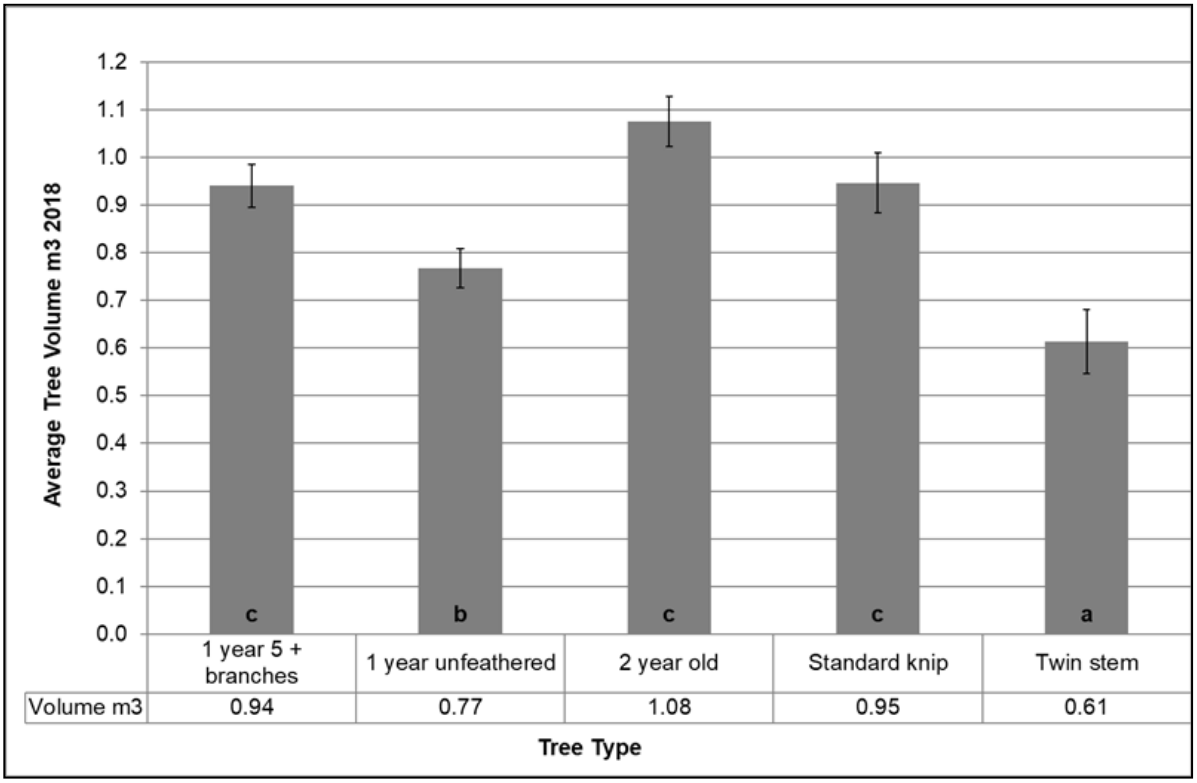


Figure 10. Tree Volume (m³) in 2018 for five different tree types. Results with different letters are significantly different from one another (P=<0.0001)

Yield efficiency

Yield efficiency was calculated after assessments were completed in 2018.

In 2018, the yield efficiency varied between 42.7% (2 Year Old) and 57.4% (Twin Stem). Yield efficiency decreased in 2018 (Figure 11).

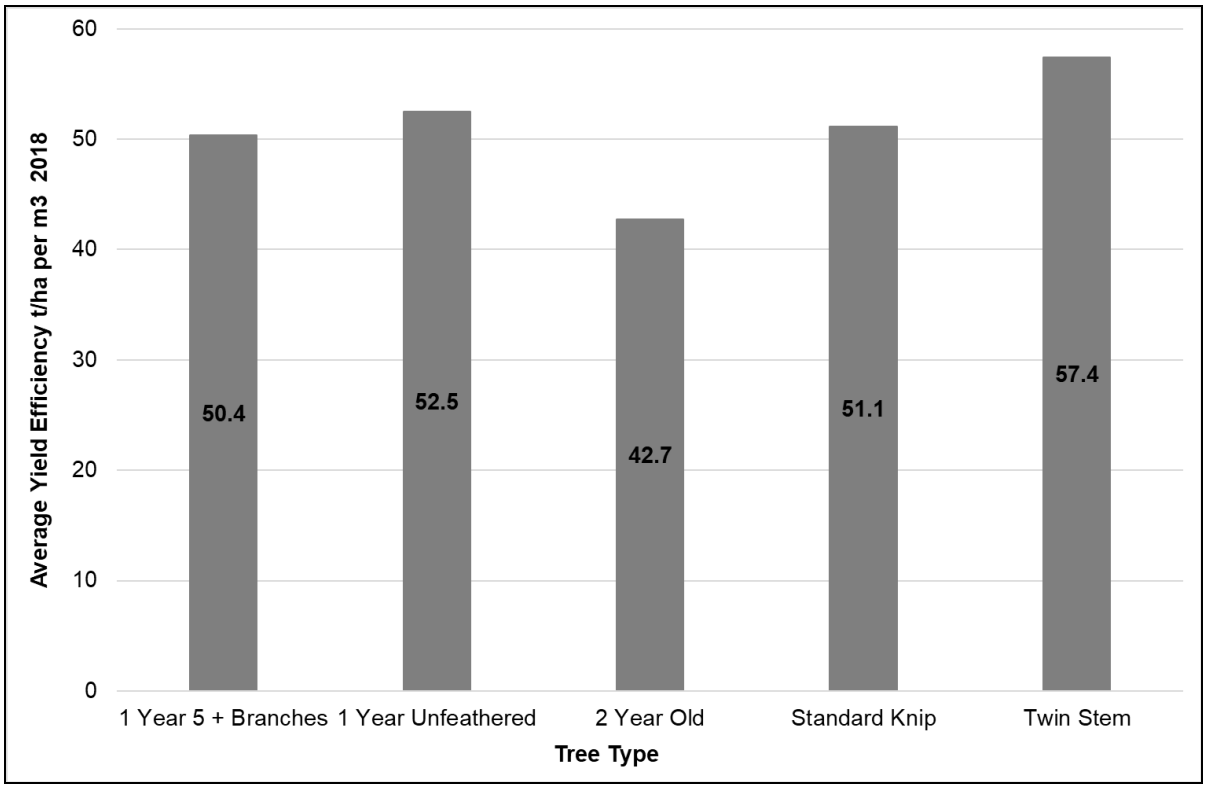


Figure 11. Yield efficiency (t/ha per m^3) in 2018 for five different tree types

Discussion 2018

The growth extension period in which the nine fully expanded leaf stage was reached in 2018 was short.

There were significant effects of tree type on all yield assessments in 2018. However, average yields were lower in 2018 compared to 2017.

Total yields per tree type during 2018 were again variable. Twin Stem trees were again the lowest yielding trees. Total yields for the other tree types were statistically similar.

Twin Stem had the highest yield per tree in 2018 and its yield per stem was statistically similar to One-Year Unfeathered.

Class 1 yield (t/ha) in 2018 was lower than 2017 for all tree types. Trees had moderate crop loads.

The cumulative total yield profile remained similar between tree types in 2018 although One-Year Unfeathered was statistically similar to One-Year Five-plus-Branches and Two-Year Old Trees for the first time.

Disease pressure in the trial's orchard plot was moderate in 2018. Class 1 percentages were commercially acceptable and >80% for all tree types in 2018. Most Class 2 fruit was due to russet and disease and most Waste fruit was due to size, damage or disease. Percentages of marketable fruit (Class 1 and 2) were >90% for all tree types.

Average fruit weight was acceptable in 2018: >120g for all trees types except One-Year Five-plus-Branches (118.5g). There were no significant effects of tree type on average fruit weight.

Average fruit size in 2018 was acceptable with reasonable percentages of fruit sized 60 mm to 70 mm (60% to 73%). There were low percentages of fruit <60mm and very low >75mm, but moderate quantities between 70mm and 75mm (15% to 26%).

All tree types increased in height between 2017 and 2018. One-Year Five-plus-Branches and Two-Year-Old trees decreased in average spread in 2018. 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 One-Year Unfeathered.

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

Conclusions 2018

- Statistically significant results of various assessments were again observed in 2018
- Rapid shoot growth was likely due to optimal conditions during that crop growth stage – warm day and night time temperatures plus adequate soil moisture
- Class 1 yields (t/ha) had decreased for all tree types meaning commercial expectations of >45 t/ha were not met
- The decrease in Class 1 yield (t/ha) in 2018 may be due to sub-optimal Fruit Wall pruning in 2017 and/or 2018. It may have been carried out too late therefore not allowing sufficient time or resources for bud formation in 2017 (although previous timings have been successful). Alternatively, too much cropping wood may have been removed in 2018. Poor pollination due to the extreme wet and windy weather during flowering in 2018 may also have been a factor together with colder night time temperatures and fluctuating day time temperatures

- However, since fruit set assessments were not carried out, yield reduction could have been caused by environmental conditions
- Growers must robustly monitor crop growth stage and assess bud formation i.e. not cut at exactly the same point each year
- The mean yield of One-Year Unfeathered tree type was not statistically different from similar mean yields indicating that its production has caught up with other tree types. Given that it has taken 4 years to do so, it may not make One-Year Unfeathered trees a first choice for growers and profitability. However, yield efficiency must also be considered
- The higher percentage of small fruit in 2018 compared to 2017 was likely due to the hot weather and lack of soil moisture in this unirrigated orchard plot
- General tree volume increases in 2018 indicate that the trees have recovered from the inter pruning in 2017 (which decreased volume, but which may have stimulated regrowth)
- The lower tree volume for Twin Stem and One-Year Unfeathered tree types is due to slower establishment and continuing disease for Twin Stem (likely acquired in nursery as other tree types are much less affected) and the delayed overall development of cropping wood for One-Year Unfeathered (which were small trees, 'whips', at planting)
- The lower yields for Twin Stem trees in 2018 may have been a combination of disease prevalence and the loss of further diseased previously cropping wood, robustness of tree and lack of regrowth

Results Summary and Discussion 2014 - 2018

Leaf Counts

The timing of the fruit wall pruning at nine fully expanded leaves on new shoot growth varied between 7 June and 1 July over the five year trial. However, the date on which the nine leaf average was reached varied between 5 and 24 June.

Yield

Twin Stem trees had statistically lower total yields per tree type (all rows) than all other tree types in all five seasons of the trial except for One-Year Unfeathered in 2014 and 2015. One-Year Unfeathered had statistically lower total yields than all other tree types except Twin Stem until 2017. In 2018, total yields were statistically similar for all tree types except Twin Stem.

Yield per tree was statistically higher for Twin Stem in all years, except 2014 when values were statistically similar to all other tree types except One-Year Unfeathered (which maintained a statistically lower yield per tree than any other type).

Yield per stem was statistically lower for Twin Stem and One-Year Unfeathered tree types in every year of the trial, except 2018 when Twin Stem remained statistically lower than all other tree types and One-Year Unfeathered was statistically similar to One-Year Five-plus-Branches and Two-Year-Old trees.

Class 1 yield (t/ha) was only assessed in the final year of the trial. Even the highest yielding tree type (Standard Knip – 40.6 t/ha) was below commercial expectations of a Gala orchard in its fifth fruiting year. Twin Stem had significantly lower Class 1 yield (t/ha) than any other tree type. One-Year Five-plus-Branches, One-Year Unfeathered and Two-Year-Old tree yields were not statistically different.

Cumulative yields total t/ha for 2014-2018 were variable. Two-Year-Old trees had the highest cumulative yields of 194.9 t/h and One-Year Unfeathered the lowest of 139.7 t/ha.

However, the difference between tree types of the highest and lowest total yield t/ha remained consistent in each year (ranging from 14.6 to 11.6 t/ha and with an average of 13 t/ha over the whole project).

From 2013 to 2016, One-Year Unfeathered had the lowest total yield. In 2017 and 2018 Twin Stem had lowest total yield.

Numerical differences between the highest and lowest yielding tree type remained numerically and statistically similar between 2014 and 2018.

Quality

Marketable fruit quality for all tree types was high for the years 2015-2018. Marketable yields for all tree types were over 90% for all years of the trial except 2014. Disease pressure (scab) and incidence was high in 2014 and the highest marketable yields of 60.8% and Class 1 34.7% were achieved by One-Year Unfeathered trees. In 2014, Two-Year-Old trees had the highest Waste of 57.9% and other tree types had >40% Waste except One-Year Unfeathered. However, in 2015 (when disease pressure was lower), Two-Year-Old trees had the highest Class 1 fruit (73.3%) and all other trees yielded above 65% Class 1 fruit. The highest marketable yield in 2015 was for Twin Stem (94.9%). This trend continued in 2016 when (despite high disease pressure and incidence) all tree types had >70% Class 1 yields, One-Year Unfeathered had the highest Class 1 yields (83.7%) and Standard Knip the highest marketable yields of 94.1%. Class 1 yields in 2017 had decreased for most tree types with Standard Knip highest at 80.4% and One-Year Unfeathered had the highest

marketable of 95.4%. In 2018, Class 1 yields had improved for most tree types and Twin Stem had the highest of 84.1%. The highest marketable yield in 2018 was for One-Year Unfeathered (95.4%).

Average fruit weight

There were significant effects of tree type on average fruit weight in 2014 and 2015 only. Twin Stem trees had heavier average fruit weight than any other tree type in 2014 (147.7g). Other tree types' fruit averaged between 125g and 135g in 2014. In 2015 Twin Stem average fruit weight was statistically similar to One-Year Unfeathered. Average fruit weight was below 120g for all tree types in 2015 and 2016. In 2017 and 2018 average fruit weight was above 120g for all trees types except Two-Year-Old (116.5g in 2017) and One-Year Five-plus-Branches (118.5g in 2018).

Average fruit size

Average fruit size was calculated for all fruit classes (1, 2 and Waste) in 2014 and on Class 1 fruit for 2015-2018. In 2014, over 40% of fruit for all tree types was above 70 mm (total average fruit size) and only 50% of fruit was within the 60mm-70mm size band (except Twin Stem which was 38.5%). In 2015, percentages within the 60mm-70mm band for Class 1 fruit were between 68.4% (Two-Year-Old) and 74.1% (One-Year Five-plus-Branches) with only 9.8% (One-Year Five-plus-Branches) to 24.6% (Twin Stem) of Class 1 fruit above 70 mm. Average Class 1 fruit size in 2016 was small due to below average rain fall from July to October and high average temperatures in August and September (FAST & Met Office 2016). Between 25% (Standard Knip) and 37.5% (One-Year Five-plus-Branches) of fruit was in the <60mm category and only 57.9% (Two-Year-Old) and 71.3% (Standard Knip) of fruit was between 60 mm and 70 mm. Average Class 1 fruit size in 2017 was large with between 19.6% and 29.2% (Two-Year-Old and Standard Knip) of fruit >70mm and only 63.5% and 72.9% (Standard Knip and Two-Year-Old) of fruit between 60 mm and 70 mm. This trend continued in 2018 despite a heavy crop load. Between 60.7% and 73.1% (Standard Knip and One-Year Five-plus-Branches) of Class 1 fruit was between 60 mm and 70 mm in 2018 and 16.4% to 29.6% (One-Year Five-plus-Branches and Standard Knip) was over 70 mm.

Height, spread & volume

There were significant effects on tree height, spread and volume in every year of the trial. Average height increased every year for all tree types and 3.0 m had been achieved by 2018 except for One-Year Unfeathered (2.607 m) and Twin Stem (2.654 m). These two tree types consistently had statistically lower heights than others. Two-Year-Old had significantly

greater average tree height compared to all other tree types in 2015 and 2016. Average tree heights were statistically similar for One-Year Five-plus-Branches, Two-Year-Old and Standard Knip in 2017 and 2018.

The width of the lower tree canopy was measured in the winter after each fruiting season. The average spread for all tree types increased between 2014 and 2015 after which it decreased and was maintained at an overall average of 110 cm. Two-Year-Old trees had the highest spread in every year and Twin Stem the lowest. From 2014 to 2017, Twin Stem and One-Year Unfeathered had statistically lower average spread than any other tree type. From 2015 to 2017, Two-Year-Old had statistically higher average spread than any other tree type except Standard Knip.

Twin Stem and One-Year Unfeathered had statistically lower average tree volume than all other types from 2014 to 2017. Two-Year-Old trees had statistically higher average volume than all other tree types except Standard Knip from 2015 to 2017. Results for average volume in 2018 were statistically similar for One-Year Five-plus-Branches, Two-Year-Old and Standard Knip.

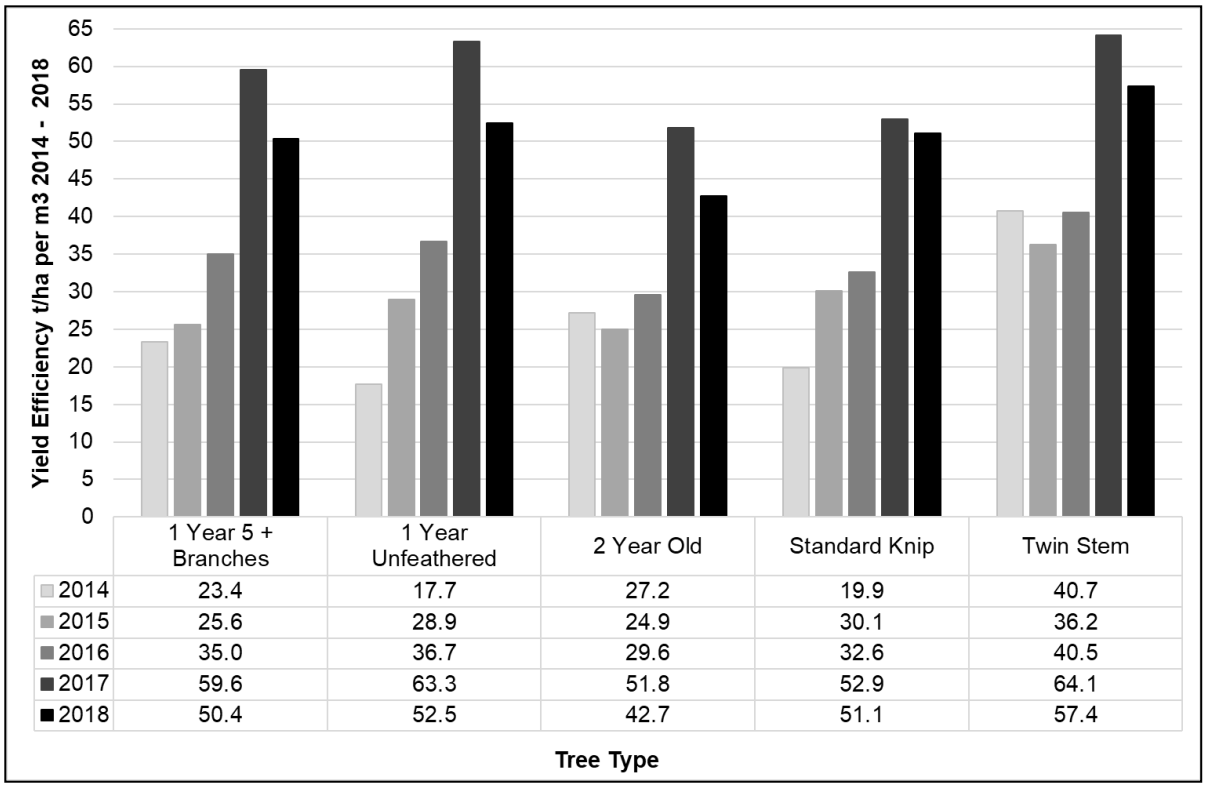
Yield Efficiency

Yield efficiency is a tool to predict potential yield and a method of assessment of the relative productivity per area. It allows for direct comparisons of trees of varying sizes without the need to account for manipulation of the canopy (i.e. via pruning).

Twin Stem trees maintained the highest yield efficiency throughout the trial. Two-Year-Old trees had the lowest yield efficiency in every year except 2014. Whilst One-Year Unfeathered trees had the lowest yield efficiency in 2014, by 2016 it had the second highest. Yield efficiency increased between 2014 and 2017 for One-Year Five-plus-Branches, One-Year Unfeathered and Standard Knip trees. Yield efficiency for Two-Year-Old and Twin Stem trees decreased between 2014 and 2015. Yield efficiency was lower in 2018 than 2017 for all tree types (Table 14 and Figure 12).

Table 14. Yield efficiency t/ha per m^3 for five different tree types for five years (2014-2018).

TREE TYPE / YIELD EFFICENCY (T/HA / M^3)	2014	2015	2016	2017	2018
1 Year 5 + Branches	23.4	25.6	35.0	59.6	50.4
1 Year Unfeathered	17.7	28.9	36.7	63.3	52.5
2 Year Old	27.2	24.9	29.6	51.8	42.7
Standard Knip	19.9	30.1	32.6	52.9	51.1
Twin Stem	40.7	36.2	40.5	64.1	57.4



	1 Year 5 + Branches	1 Year Unfeathered	2 Year Old	Standard Knip	Twin Stem
2014	23.4	17.7	27.2	19.9	40.7
2015	25.6	28.9	24.9	30.1	36.2
2016	35.0	36.7	29.6	32.6	40.5
2017	59.6	63.3	51.8	52.9	64.1
2018	50.4	52.5	42.7	51.1	57.4

Figure 12. Yield efficiency t/ha per m^3 for five different tree types for five years (2014-2017)

Final Conclusions 2014 – 2018

- Based on early yields compared with predicted returns and considering tree costs, Two-Year-Old, Standard Knip and One-Year Five-plus-Branches may be more profitable than One-Year Unfeathered and Twin Stem for growing in a Fruit Wall system at the same tree height and alley width as in the trial
- However, whilst Twin Stem and One-Year Unfeathered trees in this trial had statistically lower volumes and yields than the other tree types, were slower to establish and had higher incidences of disease, their higher yield efficiency suggests that they could be grown at significantly increased densities via reduced inter row spacing and alley widths and lower canopy height without yield reductions (e.g. 6,667 trees per hectare, 0.6 m x 2.5 m and <2.5m)
- Based on results from this trial, there would be minimal value to the grower until the fourth or fifth fruiting year of a similarly established new Fruit Wall managed orchard, given the consistently lower marketable yields compared to standard commercial expectations of hand pruned trees

- Increased long term returns are unlikely based on results from this trial and predicted potential yield increases from the best tree type for Fruit Wall systems may be unrealistic
- Growers should be able to reduce pruning costs from the reduced labour input required by mechanical pruning (which could be also be used to convert existing orchards or as part of a husbandry management programme)
- Mechanically pruned orchard systems grown with a significantly further reduced profile and reduced alley width could be beneficial with the introduction of mechanised harvesting

Pruning was delayed in some years and, in reality, growers may be faced with a similar logistical problem. Sub optimal pruning (timing and quantity) could negatively affect bud initiation.

Differences in yields (total, per tree and per stem) were due initially to tree type and intermediately to tree type and responses to the Fruit Wall management. Latterly, responses to Fruit Wall management diminished as trees matured and fruiting wood increased.

Yield variability in the early years between tree types was predicted. Results indicate that differences have been reduced in the final year of the trial. It is expected that differences would continue to diminish further.

Twin Stems have higher yields per tree because they have two stems rather than one. In this trial the Twin Stems had a higher incidence of disease and fruiting wood and stem height was lost. Increased yields should be expected in other orchards with healthier trees making Twin Stems a viable profitable option even given the increased tree and planting costs as this will be balanced by the higher yield efficiency.

Yield responses in more vigorous orchards may be different and should be higher than the trial orchard.

The lack of statistical significance in average fruit weight in the latter years of the trial are likely due to the prolonged Fruit Wall management rather than tree type.

Large average fruit size in the early years was due to lack of fruiting wood and fewer fruit per tree. Smaller fruit size in 2016 was due to climatic conditions.

At the conclusion of the trial, most tree types were maintaining commercially acceptable fruit weights (of ≥120g).

Fruit size in irrigated orchards will be easier to maintain.

The significant effects on tree height, spread and volume were due to the different tree types and establishment. Once further matured and canopy voids are filled with fruiting wood, differences are likely to be reduced.

The decreases in average spread were due to the effect of the Fruit Wall management and indicate that after the second fruiting year the lower canopy had established.

A different assessment of tree volume such as Leaf Wall Area or Porosity may be a more accurate method for estimating and revealing differences between tree types in the development of cropping wood.

Decreases in yield efficiency for Two-Year-Old and Twin Stem trees in the early years would indicate that fruiting wood was lost – either due to pruning of more advanced Two-Year-Old material or from disease (Twin Stems).

Objectives

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

A. To select five 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 five cropping years by recording yield and grade out.
   Achieved through assessments and records between 2014 and 2018.
C. To measure tree volume by recording height and spread each year.
   Achieved through assessments and records between 2014 and 2018.
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.
   Achieved through assessments, records and reports between 2014 and 2018.
E. To communicate the results of the trial via grower meetings, AHDB News articles and open day at the trial site.
   Achieved via AHDB 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, 2018 and 2019.

Knowledge and Technology Transfer

Results have been presented at the:

- AHDB Tree Fruit Day for Agronomists in 2016 and on 22 February 2018 and 28 February 2019 (Abi Dalton, Trials Manager).

- AHDB Open Day August 2017 (Abi Dalton, Trials Manager).
- FAST LLP Members' Conferences in February 2015, 2016 and 2017 (Abi Dalton, Trials Manager).
- An article for the AHDB Grower magazine was submitted in 2014, 2015, 2016 and February 2017 for publication.

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APPENDIX 1: PHOTOGRAPHS 2014-2018

One-Year Five-plus-Branches

2014 before nine leaf cut

2014 after nine leaf cut

2015 before cut

2015 after cut

2015 at harvest

2016 before cut

2016 at harvest

2018 before cut

2018 after cut

2018 at harvest

One-Year Unfeathered

2014 before nine leaf cut

2014 after nine leaf cut

2015 before cut

2015 after cut

2015 at harvest

2016 before cut

2016 after cut

2016 at harvest

2018 before cut

2018 after cut

2018 at harvest

Two-Year-Old

2014 before nine leaf cut

2014 after nine leaf cut

2015 before cut

2015 after cut

2015 at harvest

2016 before cut

2016 at harvest

2018 before cut

2018 after cut

2018 at harvest

Standard Knip

2014 before nine leaf cut

2014 after nine leaf cut

2015 before cut

2015 after cut

2015 at harvest

2016 before cut

2016 after cut

2016 at harvest

2018 before cut

2018 at harvest

Twin Stem

2014 before nine leaf cut

2014 after nine leaf cut

2015 before cut

2015 after cut

2015 at harvest

2016 before cut

2016 at harvest

2018 before cut

2018 after cut

2018 at harvest