Project title:	Developing Practical Strategies to Improve Quality and Storage Potential of UK Apples
Project number:	TF225
Project leader:	Dr Richard Colgan - Natural Resources Institute, University of Greenwich
Report:	Annual Report October 2018 (for 2017)
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Key staff:	Debbie Rees, Chris Atkinson NRI - University of Greenwich Julien LeCourt - NIAB-EMR Abi Dalton - FAST LLP Mehrdad Mirzaee, Mark Tully, Colin Carter - Landseer
Location of project:	NIAB/EMR, FAST LLP, Selected Gala orchards in Kent
Industry Representatives:	Nigel Jenner, Paul Smith and Nigel Stewart
Date project commenced:	1 April 2016
Date project completed (or expected completion date):	31 March 2021

DISCLAIMER

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

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.

Dr Richard Colgan

Reader in Post-harvest Physiology

Natural Resources Institute, University of Greenwich

Signature ....Date 14-11-2018................................

Dr Julien Lecourt

Post Doctoral Research Scientist

NIAB-EMR

Signature ....Date ....

Dr Mehrdad Mirzaee

Technical Manager

Landseer Ltd

8/11/2018

Signature ....Date...

Abi Dalton FdSc

Trials Manager

FAST LLP

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

Report authorised by:

Name

Position

Organisation

Signature .... Date ....

Name

Position

Organisation

Signature .... Date ....

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GROWER SUMMARY

Headlines

- The position of fruit within the tree canopy influences the accumulation of fruit dry matter content.
- Fruit with higher dry matter entering storage maintained higher °Brix throughout Controlled Atmosphere storage (3% CO_2: 2% O_2).
- An increase in light penetration and interception was recorded in centrifugal pruned trees, but it was too early to see changes in Fruit Dry Matter.
- A weak correlation occurred between higher K and Mg and increases in Fruit Dry Matter.
- Chlorophyll fluorescence has the potential to track changes in harvest maturity.

Background and expected deliverables

Fruit dry matter (FDM) content is considered a good indicator of high sugar and acid content (°Brix) and eating quality of apples at harvest. Apples high in FDM tend to retain quality attributes over extended periods of storage. The extent to which orchard management practices during flower bud and fruit development affect FDM at harvest requires further attention. Moreover, the relationship between FDM and fruit quality ex-store throughout the storage season, is of interest to the UK apple industry and may afford the opportunity to identify orchard consignments that can be stored for longer.

Several research groups, including the work of Palmer (1999) in New Zealand, have linked high FDM at harvest to good quality and good storage potential. These studies were reviewed in AHDB Horticulture Project TF 222, and although previous research highlights the potential to use FDM as a proxy measure of fruit quality, much of this work was correlative.

The underlying basis of this relationship needs to be better understood so that it can be manipulated to deliver premium fruit quality. This project set out to improve our understanding through a series of Work Packages:

1. A meta-analysis of existing data sets to obtain a greater understanding of the factors controlling both FDM and quality
2. The effect of reflective mulches and novel pruning strategies on light interception in the crop canopy and its effect on FDM
3. Manipulation of crop load through bud and fruit thinning to assess impact on FDM and help growers to improve the quality of stored apples.

In addition, the project set out to investigate a new method of recording fruit maturity using chlorophyll fluorescence (Work Package 4) to improve the methods for predicting the optimum date for picking fruit destined for long-term storage.

Summary of the project and main conclusions

Meta-analysis of data sets

Meta-analysis (Work Package 1: UoG / FAST LLP / NIAB EMR) for the two years of FDM data for commercial Gala and Braeburn orchards identified 56 Gala orchards where mineral analysis (soil or leaf) existed to allow some correlative analysis of FDM against soil and leaf quality attributes. Use of multiple regression linear models revealed a weak positive relationship between fruit Potassium and Magnesium concentrations and FDM and a negative relationship with Zinc.

The effect of reflective mulches and novel pruning strategies on FDM

Conversion of tall spindle (TS) trees to a centrifugal growth habit was undertaken in the winter of 2016 as part of Work Package 2 (NIAB EMR). In the first year of conversion, Centrifugal System (CS) increased light interception with 41.5% of external light compared to 34.4% in the tall spindle system. In the first year, yields in CS trees were lower - 45 kg/tree compared to 61 kg/tree in TS trees, but it is anticipated that yield will increase as future pruning of CS trees will be minimal. The use of reflective covers increased yields in CS trees by 5% and TS trees by 19% exemplifying the benefits of increased light penetration and interception on fruit production. The proportion of Class I fruit was 84.5% in CS trained trees compared with 80.9% in TS systems.

Manipulation of crop load through bud and fruit thinning

In the second year of Work Package 3 (FAST LLP / UoG), a series of bud, flower and fruitlet thinning practices were implemented using the following treatments:

T1: Untreated Control – no thinning

T2: Bud Thinning - buds were removed in late March at BBCH 52-54 (end of bud swelling to mouse ear)

T3: Mechanical Thinning – in April using a hand held Electroflor machine applied at BBCH 65-66 (60% first open flowers)

T4: Chemical Thinning - Exilis (6-Benzyladenine) + Fixor applied in May at BBCH 70-72 (funded by Fine)

T5: Chemical Thinning - Brevis (150 SG metamitron) applied in May at BBCH 70-71 & 71-72 (funded by Adama)

T6 Standard Hand Thinning – removal of fruitlets to doubles & singles within clusters, applied at BBCH 71-72 (fruit size 15mm to 25mm, pre/up to second fruit fall)

T7 Hand Thinning Size – removal of fruitlets based on size category starting at BBCH 73, event 1 fruit size 25mm to 30mm, event 2 fruit size 40mm (BBCH 74).

T8: Late Hand Thinning treatment - BBCH 73-74 (fruit size 30mm to 40mm, after second fruit fall)

No treatments significantly increased FDM at harvest in the first year. Application of Brevis led to a doubling of fallen fruit (237/tree) compared to the control (115/tree) and represented 20% of the total fruit on the tree. Standard hand thinning and late season thinning led to more fruits being physically removed than thinning to size. None of the treatments significantly affected yield or the proportion of Class 1 fruit. In 2017 the trial trees were subjected to frost damage so it is likely that treatment differences may have been supressed by the higher volume of natural flower/fruit drop.

Chlorophyll fluorescence as a system for predicting optimum picking dates

For Work Package 4 (Landseer Ltd), Chlorophyll fluorescence (CF) modelling was successful in predicting the onset of harvest maturity by 7 to 10 days in advance of starch clearance patterns reaching 75-80% in six commercial Gala orchards.

Advanced warning of the onset of starch clearance would allow growers more time to organise harvest and increase the likelihood of a greater proportion of the first picked Gala crop being harvested within the short window necessary to ensure fruit are suitable for long-term storage. Chlorophyll fluorescence modelling was successful in predicting the onset of harvest maturity by 7 to10 days in advance of starch clearance patterns reaching 75-80%. Landseer monitored changes in CF profiles in six commercial Gala orchards starting from mid-July, at fruitlet stage, through August and again at harvest. While optimising harvest maturity is important for selecting orchards for long-term storage, fruits need to have adequate balance of mineral nutrition and good FDM to improve the chances of fruits retaining quality for longer in store.

Chlorophyll Fluorescence affords an opportunity to provide information to growers regarding changes in fruit maturity in advance of changes in starch clearance patterns. Analysis of CF outputs from six commercial orchards found that on average CF outputs could predict the decrease in starch to 75% content 7 to 10 days before the event. Further work is ongoing to determine the impact of early warning and potentially more precise harvesting forecasting on the storage quality of fruit.

Main conclusions

Year 2 of this study attempted to maximise Fruit Dry Matter (FDM) in Gala by manipulating crop load through bud and fruitlet thinning practices and increasing light interception by the tree canopy by manipulating tree architecture through imposing novel centrifugal training systems in conjunction with positioning of reflective covers in alleyways. In this initial year of conversion centrifugal pruning increased light interception through the canopy but it was too early in the conversion process to observe an increase in FDM. Manipulation of crop load, while affecting yield and the proportion of class I fruit, did not lead to an increase in FDM.

Statistical analysis of a large data set provided by FAST LLP, indicated a small positive correlation between higher fruit K and Mg content and higher FDM.

The use of a chlorophyll fluorescence and subsequent data modelling provided a 7-10 advanced warning on changes in starch clearance patterns that are used by the industry as a measure of advancing fruit maturity and the need to the start of harvesting.

Financial benefits

No financial benefits have been identified to date.

Action points for growers

- Harvesting fruits higher in the canopy separately will provide consignments with higher FDM.

SCIENCE SECTION

Introduction

Improving the quality of stored apples and pears is an important priority area for AHDB Horticulture. A key indicator of fruit quality and storability is thought to be fruit dry matter content (FDM) as recent studies have suggested there is a good correlation between the FDM of apples and the ex-store sugar levels and eating quality (Harker et al., 2009; Jordan et al., 2000; Palmer et al., 2010).

Several research groups have linked high FDM at harvest to good quality and good storage potential; FDM is a reflection of fruit carbohydrate content, where soluble solids content (SSC) and starch are the major constituents. The hydrolysis of starch into SSC during fruit ripening makes FDM a valuable and accurate indicator of potential postharvest SSC, or of actual SSC once hydrolysis is complete (Jordan et al., 2000; McGlone and Kawano, 1998; McGlone et al., 2003).

FDM is influenced by tree and fruit physiology and significantly affected by environmental conditions within and between seasons and cultural practices. Further research in this area is required to determine how environmental conditions and management practices employed during growth and development affect FDM at harvest and during storage and to determine the relationship between FDM and fruit ex-store quality for UK fruit.

Fruit and tree development is the result of the interaction of diverse cultural practices (e.g., pruning, thinning, pest and disease management), environmental inputs (e.g., water, nutrition, light, [CO_2]) and physiological processes (e.g., light interception, photosynthesis, respiration, transpiration) (Wünsche and Lakso, 2000a), overlaid on the inherent genetic traits of the cultivar. These processes affect preharvest fruit development and influence how fruits at harvest appear, taste, and perform in storage (Kader, 2002). Increasing FDM in fruit must not be at the detriment to other quality parameters; consumer preferences for sweeter apples is only true where fruit firmness is retained (Harker et al., 2008).

Approximately 90 percent of FDM is composed of soluble and insoluble carbohydrates (Suni et al., 2000). The main soluble carbohydrates determining SSC of apple juice contains a mixture of fructose, glucose, sucrose, sorbitol, organic acids, and inorganic salts (Kingston, 1992; Wills et al., 2007). The ratio of sugars varies depending on the cultivar (Wu et al., 2007) and influences taste. Fructose is sweeter that sucrose, which is sweeter than glucose (Kader, 2002). The proportion of sugars depends on the source/sink relationship between leaves and adjacent fruits and on the proportion of sorbitol and sucrose entering fruit. Sorbitol makes up 80% of the photosynthate entering fruit, the balance being sucrose. Sorbitol breaks down inside the cells to fructose, while the disaccharide sucrose breaks down to equal measures of fructose and glucose. Often glucose is more readily metabolised than fructose, leaving the concentration of available glucose (0.8 - 1.0% fresh weight (FW)) inside cells rather small compared to fructose (3.9 - 5.7% FW) with sucrose concentrations between 3.5 and 4.6% FW (Ackermann et al., 1992).

The balance between crop load and vegetative growth is key to maximising FDM. However, root biomass and, in particular, the influence of carbohydrate reserves in roots should not be overlooked. Castle (1995) reviewed the literature on the impact of rootstocks on fruit quality for citrus and deciduous fruit crops;

rootstocks will influence canopy management and nutrition uptake and thus will impact on crop load and fruit size and storage potential of fruit. The impact of thinning, pruning or rootstocks on fruit quality attributes is often difficult to estimate without considering the impact of crop load; statistical techniques such as analysis of covariance have helped to quantify the influence of rootstock on fruit quality, taking into account variability in trees crop load. Drake (1988) compared cv. Gold Spur apples grafted onto various rootstocks; M9 and M27 produced the firmness fruit and the highest °Brix in juice samples.

Some of these studies were reviewed in AHDB Horticulture (TF 222: Correlation between harvest Dry Matter Concentration and Ex-Store quality in a range of UK grown apples and pears) and although previous research highlights the potential to use FDM as a proxy measure of fruit quality, much of this work was correlative.

The underlying basis of this relationship needs to be better understood so that it can be manipulated to deliver premium fruit quality. This is being achieved through a combination of a meta-analysis of existing data sets to obtain a greater understanding of the factors controlling both FDM and quality, a series of field-based experiments at NIAB-EMR and FAST LLP, trials on commercial grower sites and the development of practical strategies to help growers to improve the quality of stored apples.

Many studies have been undertaken on both thinning and pruning of apple trees, such that both the optimum crop load for good yield and pruning techniques to increase light interception are well known. We will take full advantage of this knowledge in designing our experiments and trials to understand the mechanisms for optimising quality for long-term storage.

The impact of dry matter accumulation on fruit maturity is less well documented; many of the factors that influence FDM (light intensity, rootstock, pruning and crop load) can influence the rate of fruit maturation.

Fruit maturity at harvest is vital in dictating postharvest storage life and future eating quality (Kader, 2002), therefore it is important to have a better method for predicting maturity on the tree. Gala destined for long-term storage should be picked at 85-90% starch content (based on iodine staining of equatorial slices). In many instances once fruit start to ripen and starch clearance starts, then a rapid decline in zonal starch patterns of 2% a day is often observed, giving growers little time to pick orchards at optimum maturity as they often have only 1 to 2 days warning that fruits are starting to ripen. Identifying non-destructive techniques that allow growers and advisors the ability to assess maturity changes across orchards and even within the canopy of individual trees affords opportunities to have greater control of harvesting schedules and practices.

Chlorophyll fluorescence has been used in many instances to measure crop health. The fluorescence yield depends both on the concentration of chlorophylls and the state of the photosynthetic apparatus (Chloroplasts). Thus, in some cases physiological stress can lead to an increase in fluorescence yield as the mechanisms of photosynthesis within the chloroplasts become less efficient and therefore less absorbed light energy can be used to drive the process, while on the other hand as fruit tissues mature or green vegetables senesce the loss of chloroplasts leads to a decrease in fluorescence yield. It is this reduction in fluorescence yield that is being investigated in this project as an indicator of apple fruit storage potential. The same techniques to measure changes in fruit maturation have been reported previously (Rees et al. 2005).

Recent work on fruit quality commissioned by AHDB

AHDB commissioned a series of reviews on the relationship between FDM and fruit quality on thinning methods and on future research needs for improving the storage quality of UK apples and pears. The objectives of this proposal have been developed based on these reviews and from the findings of a series of projects commissioned by AHDB over the past few years that have focused on improving quality of apples and pears.

The AHDB projects TF 213, 221: Extend the marketing period of Gala apples (led by NRI) studied the relationship between quality characteristics and volatile components on consumer acceptability as well as factors affecting quality after storage. Over a two-year period, consumer acceptability of UK Gala from a selection of Gala orchards found that fruit with higher FDM at harvest equated to higher °Brix at harvest and to a better °Brix coming out of store. Fruit with °Brix in excess of 13.5° were considered in many cases to have equal overall acceptability with imported fruit in late April/early May. UK fruits generally have better firmness and acidity and, where °Brix was equal to imported fruit (13.5°), were considered more acceptable despite being lower in the complement of volatiles. Taste-odour interactions lead to complicated changes in perceived flavour. Increasing sucrose concentrations can reduce perceived levels of bitterness and sourness and in addition increased sweetness can increase the perception of fruity aromatic flavours. The ability to market fruit into late May and early June is dependent on selecting the high FDM yielding orchards and storing them in regimes that maximise taste and flavour. Within project TF 221 alternative regimes were investigated that preserve taste. A number of alternative CA regimes such as 3% CO_2 2% O_2 (+ Smart Fresh (SF)) and 3% CO_2 (0.6-0.4% O_2) scored more highly than conventional regimes in taste panel assessments, despite having similar firmness, °Brix and acid ratios. Storage in oxygen <1% retained selected volatiles compared to conventional storage in 5% CO_2 and 1% O_2 where high CO_2 is known to restrict the esterification of alcohols to respective acetate esters.

Project TF 198: Developing water and fertiliser saving strategies to improve fruit quality and sustainability of irrigated high-intensity, modern and traditional Conference pear production (led by EMR) investigated the potential to develop water and fertiliser saving irrigation strategies that would also optimise Class 1 yields and fruit quality. Results over two seasons showed that FDM varied significantly between the four different growing systems in the AG Thames Concept Pear Orchard (CPO) at EMR, and that marketable yields and fruit quality were maintained or improved by alternate wetting and drying treatments. The scientifically derived irrigation scheduling guidelines developed in project TF 198 are now being tested in a project funded by Worldwide Fruit Ltd and Marks and Spencer plc on a commercial pear farm in North Kent to optimise production efficiency of high intensity Conference pear production. The potential of using deficit irrigation strategies to manipulate resource partitioning and fruit FDM was being investigated in 2016.

TF 210 and TF 214, led by EMR, are investigating the potential to use precision irrigation and targeted fertigation to improve marketable yields, consistency of cropping and fruit quality of Gala and Braeburn.

Description of Work Packages

To deliver 'Best Practice' to the top-fruit industry to improve FDM a series of work packages have been set up initially working on discrete aspects of husbandry with the aim of bringing together different components of each WP in the later stages of the project to form a single trial plot.

Background

Work package 1: To carry out a meta-analysis to provide an evidenced-based understanding of how fruit FDM can be manipulated to optimise fruit quality.

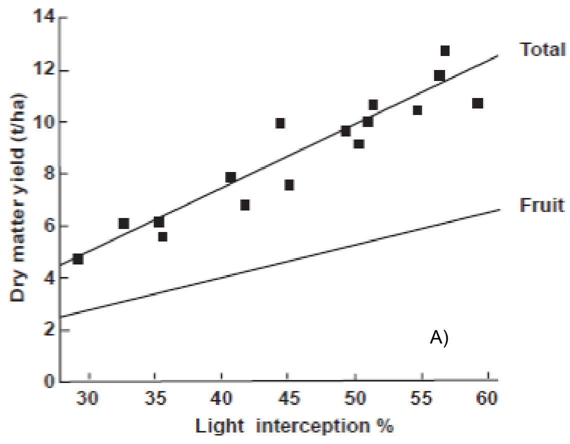
Year 1 (2016 – 2017) NRI UoG (Chris Atkinson, Stephen Young with support from Richard Colgan and Debbie Rees) and NIAB-EMR (Julien LeCourt).

Meta-analysis can be described simply as "carrying out research about previous research" in a systematic manner of review. The concept is based on combining the outputs of several diverse studies which have measured similar factors and aggregating these outputs provides more reliable and precise statistical descriptors that can help to inform appropriate outputs, e.g., crop management strategies. Meta-analysis can also help to identify causes of inconsistency between results from various studies (e.g., due to different sampling approaches) to develop new hypotheses from patterns that were not previously apparent, to find sources of disagreement in results from diverse sources and to identify potential modes of action. The latter can be particularly important in determining future route.

Work package 2: To determine the impact of increasing light interception in vertically trained high-density orchards by pruning and/or using reflective mulches at different stages of Gala fruit development on fruit quality and FDM.

Years 1- 5 (2016 – 2020) NIAB-EMR (Julien LeCourt)

Compared to many areas of tree fruit production, the productivity of UK orchards is limited by light levels (Palmer 1999). The close relationship between the amount of light intercepted by the tree canopy and fruit production is well known (e.g. Lakso, 1996, Figure 1A) and increased light interception promotes dry matter accumulation (e.g. Palmer et al. 1992, Figure 1B), total soluble sugars (TSS), fruit colouration and profitability (Jackson 1970; Robinson and Lakso 1988; Kappel and Neilsen 1994; and Lakso 1996; Kappel and Brownlee 2001). Therefore, optimising light interception in high-density orchards is critical and although different strategies are available to growers (see below), scientifically derived guidelines are needed to optimise their use in UK commercial intensive apple and pear orchards.



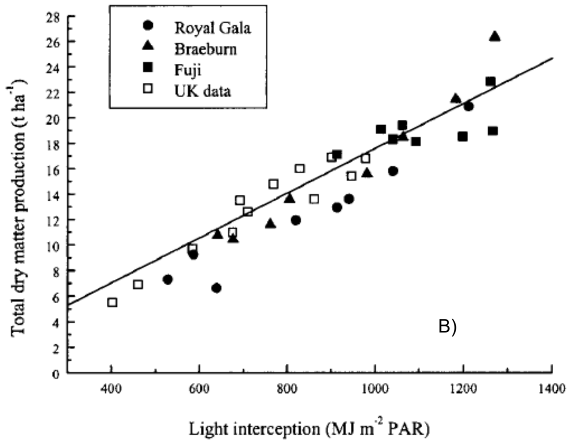


Figure 1.1 A.

Figure 1.1 B.

Figure 1.1 A. Relationship between light interception (%) and total dry matter production and FDM yield (t/ha) of Golden Delicious/M9 at East Malling. *Modified from Palmer, 1999.*

Figure 1.1 B Relationship between seasonal intercepted PAR (MJ/m^2) and total dry matter production (t/ha) of Royal Gala, Braeburn, Fuji and averaged seasonal data for the UK.

For apple, new training systems have been developed abroad and have shown promising results with regard to yield and quality. For pear, the different training systems in the AG Thames/EMR CPO have delivered a threefold increase in yield in comparison to commercial orchards, due in part to improved canopy light interception. Reflective covers or mulches can improve the amount of light intercepted by the tree canopy by up to 30% in all types of weather, with corresponding improvements in apple and pear quality and yield (Iglesias and Alegre 2009; Privé, Russell et al. 2011; Guo 2013).

Work package 3: To determine the impact of thinning strategies on fruit quality and FDM and to develop recommendations to optimise yield of high quality fruit

Years 1- 5 (2016 – 2020) FAST LLP (Abi Dalton) and NRI UoG (Debbie Rees & Richard Colgan)

UK apple growers have recently expanded their production of Gala from high intensity plantings. To accommodate additional volume, it is estimated that around 30% of this harvest must be aimed at a later market window (FAST LLP, 2016).

Improved availability of consistently high-quality fruit will enable UK growers to compete with Southern Hemisphere imports at the start of the new season window. Extending the UK Gala season by three to four weeks could generate financial returns of £2 to £3 million per year across the industry (FAST LLP, 2016).

Many studies have been undertaken on both thinning and pruning. In terms of thinning the optimum crop load for good yield of the required fruit size is known, but not the effect on FDM of achieving this optimum crop load at different times in the season. No recent work has measured any effects on FDM on Gala in the UK. Although considerable work has been undertaken to try out different pruning strategies, mainly to increase light interception and therefore yield, the effect of different tree architectures on fruit FDM and whether fruit load can be increased without reducing FDM is not yet understood.

In order to increase FDM it is necessary to understand the controlling factors. There are two periods during fruit development when carbohydrate supply (from photosynthesising leaves) can be limiting; in the first weeks (typically two to four weeks from full bloom) of fruit development and just before harvest when light levels and temperature decline. Several studies have shown that reducing crop load increases FDM of the remaining fruit (Wünsche 2000, Wünsche 2005, Sharples 1968, Palmer 1997, Kelner et al 2000). However, it would also be helpful to understand how timing of thinning affects fruit cell number (which is determined by early in fruit development) and how these impacts on quality. Photosynthate from leaves tends to be translocated to nearby fruits on the same branch/spur.

It is particularly important to develop knowledge of the impacts of the time of thinning on FDM by understanding the processes, not simply the outcomes and the former enables proposal of practical tree management strategies. Through utilising a commercial orchard with documented high fruit FDM, it will be possible to manipulate crop load based on tree age, precocity of flowering and size of branches, and quantify changes in FDM changes from flowering stages through to fruit development.

From previous studies, changes in the percentage of FDM from full bloom have been charted; a decrease after blossom is often seen, associated with high respiration rates of developing fruitlets, and then increases towards the end of the cell division phase before reaching a plateau which remains fairly stable for the remainder of the season (see Figure 2.1).

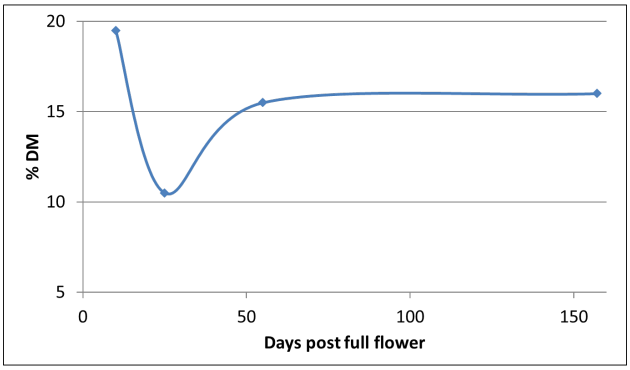


Figure 2.1. Preliminary FDM data from Gala taken during flowering and fruit development

From initial studies in two orchards the timing of thinning is thought to affect the degree to which FDM falls and rises again and potentially influence the final FDM at harvest (FAST LLP data unpublished). Many growers do not achieve the optimum crop load until late in the season - typically mid to late June through to the end of July. This trial will in subsequent years investigate the effect of achieving the optimum crop load at much earlier stages via different thinning strategies and compare with typical industry practice in terms of FDM accumulation.

The aim of the trial is to develop practical short, medium, and long-term strategies to help UK growers to optimise quality and storability of UK apples, in particular for long term storage beyond April.

This project will provide direct benefits to the growers within the project timescale as it will provide them with strategies to improve FDM.

Gala was used as a model variety to understand the relationship between quality and FDM, how to manipulate this and in order to follow changes in FDM and components during fruit development.

The initial phase (Year 1) was used to chart the changes in FDM content during the growing season and to quantify how early FDM was determined in the fruit development cycle - specifically at what point cell division ceases and starch accumulation becomes the main factor controlling FDM increase. This was achieved from detailed measurements of FDM and the components (structural carbohydrates, non-structural carbohydrates) through the cell division period. How this varies with fruit position within the tree canopy was investigated. Fruit from the 'upper' well-lit and 'lower' shaded portions of the canopy were collected from the selected orchard and how FDM varied with these different fruit positions in the tree was monitored to give insights into how the FDM progression may change. Further samples were collected at harvest time to determine how FDM may have progressed and the implications on storage potential and quality. This provided important information, not only on the reasons for initial difference in FDM, but also how it changed over the season and the implications for storage and consumer perception. It also provided an informed basis for the applications of tree management strategies, such as approaches to thinning which were considered in Year 2.

Outputs of a meta-analysis to improve the understanding of factors influencing FDM informed work on manipulating resource allocation and FDM by a range of thinning strategies to manipulate crop load at different timings. Treatment effects on the variability in FDM, its chemical components and related quality parameters within orchards and within the tree was also identified.

The review conducted on thinning technologies comes to some conclusions very relevant to this programme. For example, it is concluded that the resulting crop load is more important than the method used. It is likely that chemicals such as Brevis that inhibit photosynthesis could have effects that have not yet been identified. The review points out that thinning studies have tended to focus on crop yield and fruit size rather than quality. Another key observation is that there is a need to determine long-term effects on the trees.

Following the outcome of the experiment in Year 1 and Year 2, strategies to manipulate crop load at different timings in the selected Gala orchard were continued in Year 3 to allow targeting of optimum crop load at much earlier stages.

The timing and intensity of thinning treatments most likely to influence FDM were repeated using different hand, mechanical and chemical thinning methods and timings of events related to days after full bloom. The treatments will be applied to replicated blocks designed in consultation with a statistician.

It is anticipated that where particular treatments that thinning timing or crop load intensity has a major influence on FDM then the work package may be adapted to investigate variations in crop load compared to the typical orchard practice.

To achieve a more enlightened process orientated approach, a commercial orchard was utilised in order to follow changes in FDM and components of FDM during fruit development in 2016 (Year 1). During Years 2 to 5 of the project, different thinning treatments will be applied and it is envisaged this may increase FDM in terms of cell number and in terms of starch accumulation. This approach will enable orchard management strategies to be linked with differential changes in FDM within and between orchards.

Work package 4: Identification of the optimal harvest date of high dry matter Gala apples to deliver optimal consumer experience after extended storage under modern storage regimes.

Years 1 - 3 (2016 – 2019) Landseer Ltd (Mehrdad Mirzaee)

This work package focused on developing a non-destructive method to optimise harvest date prediction for improving the long-term storage quality of Gala.

While FDM content of fruit provides a good metric for determining the sweetness and overall eating quality of fruit, in order to maximise fruit quality at the end of storage, fruits need to be picked within a narrow harvest maturity window to ensure that the benefits of CA storage are fully maximised.

The current best practice for harvesting Gala for long term storage is to pick when starch coverage declines to 90-80% of coverage (CTIFL 3-4). Often this window in starch clearance is narrow and decline in starch occurs by 2% per day once fruits get to around 90% starch coverage.

This does not allow growers enough time to organise picking before starch levels decline further. Analysis of starch coverage is difficult to determine accurately and while there are some tablet-based image analysis software available these require calibration before harvest. Non-destructive methods such as chlorophyll fluorescence may be used as a tool for fruit maturity testing and provide an early prediction of optimum harvest date. Initial studies by Landseer indicate that the system may provide up to 7 to 10 days warning for growers to pick their fruit for long-term stored fruit.

Materials and Methods

Work package 1: Meta-analysis of Fruit Dry Matter

2017-2018 NRI UoG Chris Atkinson, Stephen Young with support from Richard Colgan and Debbie Rees, Julien LeCourt NIAB-EMR.

Data sets from FAST LLP supplied over three consecutive seasons (2015/16, 2016/17 & 2017/2018) were used to conduct a series of multiple correlation and regression analyses to identify links between mineral analysis data of fruits at harvest with the propensity to accumulate dry matter.

Initial correlation tests were performed on the 2015/2016 and 2016/2017 data sets using fruit, leaf and soil mineral analysis data correlated against FDM using a Pearson test ($p<0.05$). The analysis was performed using GGally package (ggplot2); an extension package "from RStudio" (R Core Team, 2014). Correlation coefficients were determined from Lindley and Scott (1995).

Following on from Pearson's correlation analysis a linear model using Library Lattice in RStudio was conducted. In the first instance a linear model (lm) including all minerals (lm (DM ~ Ca + N + KCA + Cu + Fe + K + Mg + Mn + P + Zn + B)) was undertaken. In order to assess the contribution of individual mineral elements within combined model, ANOVA (analyses of variance) was used to perform an analysis of the relative contributions from explained and unexplained sources of variance in a continuous response variable. Significant effects were tested with the F statistic, which assumes random sampling of independent replicates, homogeneous within-sample variances, and a normal distribution of the residual error variation around sample means (Doncaster and Davey, 2007). ANOVA was carried out to determine whether there were significant differences between minerals using RStudio (R Core Team, 2014). The mineral elements identified as having a significant effect on FDM were added in different combinations in a second series of restricted linear models. The regression models were tested against the Akaike Information Criterion (AIC) to confirm the best fit.

Work package 2. Centrifugal pruning and reflective mulches

Years 1- 5 (2016 – 2020) NIAB-EMR (Julien LeCourt)

In the Autumn of 2016, innovative centrifugal pruning and training systems were initiated and compared with a standard tall spindle tree within afour year old Gala/M9 orchard at EMR (Figures 3.1, 3.2). Within the orchards reflective mulches were laid either side of the rows after flowering to determine the effects of improved light penetration and on Class 1 yields, FDM and components of quality fruit quality (TSS, colour). The impact of pruning systems on tree architecture and canopy development are being monitored using LiDAR which can estimate tree row volume, porosity, specific leaf area and light levels studied using AccuPAR.

Figure 3.1. Pictures of the treatments applied during the experiment. The training and reflective mulches have been applied to a four year-old M9 Gala orchard located at NIAB EMR.

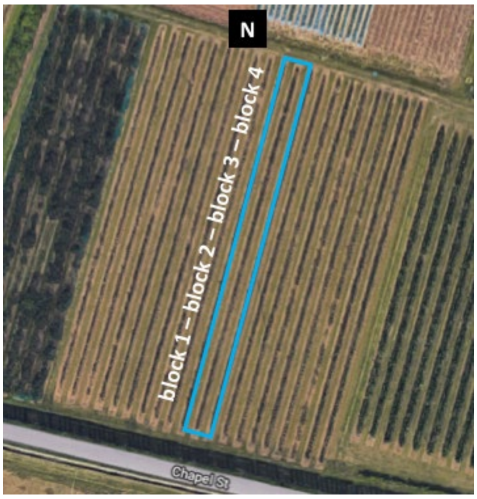


Figure 3.2. Satellite view of the area

Fruits were harvested in September 2017. Fruit was sampled from each experimental tree and categorised into 3-4 sub samples by position within the tree. Analysis of fruit quality attributes was carried out to quantify the effects of manipulating light interception on fruit FDM and quality attributes at harvest and following storage. For selected parts of the experiment in project Years 1 & 2, a more detailed categorisation will be undertaken in terms of light interception by the fruit bearing branch. Analysis of fruit quality attributes is described in WP4. Where applicable, high throughput phenotyping tools currently being developed in other IUK projects will be used to quantify treatmenteffectson aspects of fruit quality.

Post-Harvest Handling and analysis

Apples from the top and bottom of the trees under reflective covers and pruning regimes were harvested on 20 September 2017 and transferred to the Produce Quality Centre (PQC) where fruits were sampled for dry matter content and also assessed non-destructively for DM content using a Felix 750. Apples were sampled for dry matter, taking segments from opposite eighths, removing the core. Tissue was chopped into 1 cm pieces, 50 g of tissue was weighed, dried in an oven for 48 hours and reweighed. Tissue was then placed back into the oven for a further 24 hours and reweighed.

The bulk of the remaining harvested fruit was randomised within their orchard treatments and stored in 3% CO_2, 1% O_2 (0.5-1.0 °C) for 5 months, after which fruits were assessed immediately ex-store and again after seven days at 18 °C.

Work package 3: Bud, flower and fruitlet thinning strategies

Years 1- 5 (2016-2020) FAST LLP (Abi Dalton), NRI-UoG (Debbie Rees & Richard Colgan)

Location

The second year of the trial used an established Gala orchard at FAST LLP, Brogdale Farm, Faversham - Latitude 51.294933, Longitude 0.882898, Reservoir Field, Block 1B (Figure 4.1).

Figure 4.1. Aerial photograph of FAST trial orchard, Faversham.

The orchard section was approximately 0.07ha. There were four 50m long rows spaced at 3.5m with trees at 1.0m apart within the row.

Treatments

There were seven treatments and one control comprising one novel, one mechanical, two chemical and three hand thinning methods:

1. **Control**
   No thinning
2. **Bud** thinning
   BBCH 52-54: end of bud swelling to mouse ear via bud extinction using MAFCOT Equilifruit tool ratios
3. **Mechanical** thinning
   BBCH 65-66: Full flowering, at least 50% first flowers open. Pruned using hand held device
4. **Exilis** - chemical thinning
   BBCH 70-72: Fruit size up to 20mm.Fine Exilis 6-Benzyladenine + Fixor (PGR) (funded by Fine)
5. **Brevis** - chemical thinning
   BBCH 70-71 & 71-72: Fruit size up to 10mm & up to 20mm. Adama Brevis 150 SG metamitron 15% (PGR) (funded by Adama)
6. **Standard** Hand Thinning
   BBCH 71-72: Fruit size 15mm to 25mm, pre/up to second fruit fall

7. Hand Thinning to **size**

   Hand pruning event 1 at BBCH 73: fruit size from 25mm to 30mm, second fruit fall. Hand pruning event 2 BBCH 74: fruit size 40mm

8. **Late** Hand Thinning

   BBCH 73-74: Fruit size 30mm to 40mm, after second fruit fall

Trial design

The trial was made up of one area in four rows. The trial was arranged in a randomised complete block design. Each row represented a replicate block and there were four replicates per treatment. Each replicate treatment plot had three trees. There were 12 trees per treatment and 96 treatment trees in total. Guard trees were situated between replicate plots and at the ends of each row making 132 trees total (Figure 4.2.).

SOUTH

R1	**R2**	**R3**	**R4**
G	G	G	G
2	**4**	**6**	**3**
G	G	G	G
3	**1**	**4**	**2**
G	G	G	G
8	**3**	**5**	**8**
G	G	G	G
1	**2**	**7**	**4**
G	G	G	G
4	**5**	**3**	**7**
G	G	G	G
6	**6**	**2**	**6**
G	G	G	G
5	**7**	**1**	**1**
G	G	G	G
7	**8**	**8**	**5**
G	G	G	G
R1	**R2**	**R3**	**R4**

NORTH

Number	Treatment
1	Control
2	Bud
3	Mechanical
4	Exilis
5	Brevis
6	Standard
7	Size
8	Late
G	Guard tree

Figure 4.2 Trial Plan.

Applications, timing, and descriptions

Table 1.1

NO	TREATMENT	RATE WATER VOLUME	EVENTS	BBCH STAGE	DESCRIPTION, FRUITLET SIZE & CONDITIONS
1.	Control	Na	Na	Na	Na
2.	Bud	Na	1	52-54	MAFCOT Equilifruit tool used to extinguish excess buds and gain optimum per branch diameter of 5 fruits/cm^2 of trunk 160 fruits per tree
3.	Mechanical	6-7 km/ha at around 270 rpm (depending on orchard flower density)	1	65-66	Full flowering, at least 50% of flowers open
4.	Chemical Exilis & Fixor*	Exilis 3.5 to **7.5 L/ha** Fixor **100ml/ha** 100 L water	1 per year maximum application	70 -72	Fruit size up to 20mm 8 to 10mm Exilis + Fixor (no treatment above 10mm) (7 to 15mm Exilis alone) Above 15°C with increasing temperatures for 3 to 4 days after
5.	Chemical Brevis*	1.1kg/ha to **1.65g/ha** (2.2kg/ha max) 1000 L water	2 NB minimum 5 days between applications	Application 1: 70-71 Application 2: 71-72	Application 1 8-10mm Application 2 12-14mm (not made in 2017) 9-11mm optimum (8-14mm max window) lower water volumes (min 350L/ha) & no tank mixing
6.	Standard Hand Thinning	Na	1	72-73	15mm to 25mm pre/up to 2nd fruit fall (50 days post full bloom)
7.	Hand Thinning to size	Na	2	Pruning event 1: 73 Pruning event 2: 74	Pruning event 1 from 25mm-30mm. Pruningevent 2 at 40mm
8.	Late Hand Thinning	Na	1	74	30mm to 40mm after 2nd fruit fall

* Chemical thinners were applied using manufacturers’ recommendations and adapted according to conditions before, during and after applications (see product label, SDS and guidelines (Appendix 1)).

Bud thinning

Treatment 2 Bud Thinning was achieved after pruning using a MAFCOT Equilifruit tool to gain optimum buds per branch diameter. The diameter was measured at the base of each branch nearest to the trunk and the values associated with the branch size used to reduce bud numbers (Figure 4.3.).

Figure 4.3. Mafcot Equilifruit Tool.

Mechanical thinning

An Electroflor machine was used (Ins 9534 BT telescopic pole 1.3-1.8m with battery & mains charger, control & box (Agricare)). Practice was undertaken on similar Gala trees prior to thinning treatment trees to ensure consistent results (Figure 4.4.).

Figure 4.4. Electroflor machine.

Hand thinning

Treatment 7: Hand Thinning to size, involved removal of all fruit below the size required and predicted to reach optimum at harvest (63mm). This was predicted using weekly size curves from the FAST members' Top Fruit Advisory. Each of the two events involved removing fruits of different sizes from clusters which resulted in varying numbers of fruit per cluster remaining in all portions of the tree.

Treatments 6 and 8: Hand Thinning Standard and Late, were carried out by removal of fruit from clusters leaving doubles below 1.5m and singles above 1.5m.

Thinning per treatment was carried out by the same FAST Trials Team member.

No quality thinning for any treatment was carried out since it was deemed to be too subjective and there was a variable and light crop load; based on the Gala Standard of five fruits/cm^2 of trunk there were fewer than the optimum of approximately 160 fruits per tree (at 1m apart for 60 t/ha).

Crop load thinning for other treatments was also not considered in the event of over successful chemical or mechanical thinning, partially due to frost events reducing crop load.

Crop Care

The trees/plants were grown according to Good Agricultural Practice following IPM protocols. 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. Biological control was introduced as appropriate. A standard commercial nutrition programme was followed as recommended by FAST advisors and based on previous soil samples. Standard hand pruning was carried out in spring and summer pruning of the tops as required in July (Appendix 2 Chronology).

Assessments

Physiological and monitoring

- Weekly observations of the trial area were made throughout season.
- Weekly monitoring of BBCH CGS (Crop Growth Stage) on Control plots was commenced approximately 1 month prior to BBCH 53 (bud burst) and recorded continuing up to BBCH 74 (fruit up to 40mm T stage).
- Temperature, RH and PAR was monitored via SMS remote sensing equipment.

Visual

- Photographs were taken of the middle tree in each treatment plot after each fruit drop event, of fruit dropped under trees, plus prior to and after each thinning event and at harvest (relevant photographs Appendix 3).

Fruit counts

- A membrane was installed under the middle tree in each treatment plot (from wheeling to wheeling and adjacent trunks) before BBCH Stage 55 (bud thinning) and removed after BBCH Stage 74 (hand thinning late).

- Numbers of fruit naturally shed and fallen onto the membrane at each fruit drop event were counted from the middle tree in each treatment plot.
- Counts of fruit removed from the middle tree in each treatment plot at each thinning event (Treatments 6, 7 and 8 only) were recorded. Comparisons of fruit dropped naturally and deliberately thinned were made.

<u>Dry matter – pre harvest</u>

Samples were collected at 2 events prior to harvest:

- 1 week post full bloom – BBCH 70
- 11 weeks post full bloom – BBCH 74, fruits 40mm after second fruit fall (T stage) and after all thinning events

Twelve fruits per plot were removed and FDM assessed. Four fruits from each treatment tree were taken, two from each side, high and low in the canopy and from two year old wood.

<u>Harvest</u>

Starch progression was monitored weekly at three events commencing three weeks prior to the predicted harvest date (as per the FAST advisory) to accurately estimate the optimum harvest date. Ten fruits from guard trees in the trial area were selected at random at each event and processed.

Samples from each side of each treatment tree from two-year-old wood within the top, middle and bottom of canopy were collected prior to harvest for:

- Maturity - 30 fruits per treatment plot total (ten per tree, five from each side):
    - Starch
    - °Brix
    - Fruit pressures
- Dry Matter & Fruit Mineral Analysis - Twelve fruit in total (four per tree, two from each side)
- Quality - 60 fruit per treatment plot were assessed (20 per tree, 10 from each side):
    - Fruit was sorted into Class 1 and waste
    - The waste was categorised, counted & weighed (under/over size <55mm / >80mm, disease, russet, pest, misshape, physical damage)
    - The Class 1 fruit was graded according to five size classes (55- 60mm, 60-65mm, 65-70mm, 70-75mm, 75-80mm), counted & weighed
    - The percentage was calculated for waste and Class 1 fruit plus numbers in each size class

- Storage and quality (NRI) - Twelve fruit in total per plot were sampled (four fruit per tree, two from each side)

Fruit was picked per three tree plot and weighed in the field.

The average total yield kg and T/H per treatment was calculated plus Class 1 T/Ha, percentage of Class 1 and Waste, average Waste categories, Fruit Weight, Size Distribution and percentage of Starch, °Brix and Pressure (kg/mm).

Sampling and laboratory analysis NRI UoG

Samples for sugar analysis were collected by NRI at three time-points, after petal fall on 9th May, at fruitlet stage 13th July, after the final thinning treatment had been applied and at harvest. Initial samples were first weighed (Fresh weight, FW) before freezing whole in liquid nitrogen while fruitlets greater than 35 mm were sectioned and opposite eighths of cortex were frozen and stored at -80°C. Samples were then subject to freeze drying (-80°C) for 48 hours, after which samples were reweighed and a percentage FDM was calculated. Thereafter, freeze dried material was ground in either with a pestle and mortar or larger samples were powdered in a spice grinder. Samples were then subject to an analysis of sugars by extraction of 0.2g of powdered tissue in 80% ethanol for 120 minutes with periodic vortexing; following incubation, the supernatant was collected following centrifugation (12,000 rpm) and filtered through 0.45 μM syringe filters and followed by analysis of sugars by HPLC.

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/tables are shown with standard error bars (where applicable). The results of the MRTs where statistically significant effects (P value < 0.05) were evident are detailed in charts/tables with P vales and LSDs indicated.

Work package 4: Chlorophyll fluorescence to predict optimal harvest date Gala apples

Years 1 - 3 (2016 – 2019) Landseer Ltd (Mehrdad Mirzaee)

Work package 4 focused on developing a non-destructive method to optimise harvest date and identifying the orchards suitable for long term storage. This can be achieved by choosing the right fruit with high dry matter and balanced minerals that are picked at the right time for extended keeping quality during long term storage. If this process is carried out correctly then UK Gala should compete effectively with Southern hemisphere fruit, both on fruit firmness and, more crucially, taste.

Current harvesting of Gala for long term storage is to pick fruit between 85-80% starch coverage, where background red colour has developed sufficiently to satisfy the marketing desks. However, this narrow window does not allow growers enough time to optimise picking before starch levels decline further. The results in 2016 and 2017 confirmed that application of chlorophyll fluorescence as a non-destructive tool for fruit maturity offers the benefit of 7 to 10 days early warning to the optimum harvest date for long-term storage.

In the second year of trials, the CF profiles and mineral analysis and FDM of different orchards of Gala as fruitlet (25-30mm) were measured in 9 selected orchards in Kent in the first week of July 2017. Samples were taken from each compass point on a tree, North, East, South and West (four fruitlets per tree, all samples picked from middle height of trees). Samples were taken in a "W" pattern across the orchard taking samples at appropriate points.

In the first week of August sample collection fruit (55-60 mm) from nine orchards were repeated. After analysing CF, mineral profiles and FDM of fruit, according to the flow chart designed in the first year of trials for decision making about selection of the best orchards for long term storage (Figure 4.1), five orchards from different Gala clones: (Mondial, Galaxy and Schniga) were selected for monitoring two to three weeks before commercial harvest time. Since FDM and mineral analysis are reflections of orchard management and environment, these both affect fruit maturity and storability. It is essential to monitor for chlorophyll fluorescence only fruit that is intended for long term storage to obtain an accurate prediction model (Table 4.1).

Table 2.1: Comparison of dry matter and mineral analysis in 9 orchard and selecting 5 orchards for the long-term storage (season 2017-18)

FIELDREF	Test	Clone	DMC	CF (AvF)	WT	Interpretation	N	Interpretation	P	Interpretation	K	Interpretation	Mg	Interpretation	Ca	Interpretation
Orchard 1 ✓	Fruitlet (July 2017)	Schneiga	15.6	4664	36.34	Normal	87.36	Normal	13.62	Low	147.78	High	11.02	High	16.59	High
	Fruit (August 2017)		16	4703	97.71	Normal	35.2	Low	9.4	Very Low	94.28	Sli Low	7.45	Normal	10.49	High
Orchard 2 ✓	Fruitlet (July 2017)	Mondial	13.2	5665	40.22	Normal	83.16	Normal	13.21	Low	135.24	Normal	10.04	Normal	14.42	Normal
	Fruit (August 2017)		14.6	4752	103.06	Normal	39.42	Sli low	7.55	Very Low	87.9	Low	6.92	Normal	10.24	High
Orchard 3 ✗	Fruitlet (July 2017)	Galaxy	14.2	4989	48.28	Normal	55.38	Sli low	14.73	Sli Low	129.68	Normal	9.41	Normal	14.86	High
	Fruit (August 2017)		13.6	4291	111.31	Normal	36.72	Sli low	11.08	Sli Low	93.09	Sli Low	6.55	Normal	10.71	High
Orchard 4 ✗	Fruitlet (July 2017)	Galaxy	13.2	4775	43.51	Normal	80.52	Normal	13.02	Low	145.7	High	9.83	Normal	16.34	High
	Fruit (August 2017)		13.6	4553	101.74	Normal	38.08	Sli low	8.39	Very Low	86.75	Low	6.95	Normal	10.06	High
Orchard 5 ✗	Fruitlet (July 2017)	Schneiga	14	5914	47.64	Normal	81.2	High	13.45	Low	125.9	Normal	8.78	Normal	14.15	Normal
	Fruit (August 2017)		13.6	6109	85.96	Normal	48.96	Normal	9.36	Very Low	69.26	Very Low	7.11	Normal	10.69	High
Orchard 6 ✓	Fruitlet (July 2017)	Mondial	12.8	5983	46.57	Normal	67.84	Normal	13.1	Low	103.43	Sli Low	8.08	Normal	15.43	High
	ruit (August 2017)		13	5363	98.36	Normal	46.8	Normal	9.7	Low	85.76	Low	7.03	Normal	13.9	High
Orchard 7 ✗	Fruitlet (July 2017)	Mondial	14.2	4660	46.66	Normal	65.32	Normal	14.3	Sli Low	118.25	Normal	9.28	Normal	16.21	High
	Fruit (August 2017)		12.8	4726	114.86	Normal	42.24	Normal	10.45	Low	64.28	Very Low	6.04	Normal	10.17	High
Orchard 8 ✓	Fruitlet (July 2017)	Galaxy	13.6	6441	49.59	Normal	72.08	Normal	11.16	Very Low	124.99	Normal	9.3	Normal	14.59	High
	Fruit (August 2017)		13.2	5163	88.01	Normal	36.96	Low	6.48	Very Low	71.29	Very Low	6.16	Normal	10.85	High
Orchard 9 ✓	ruitlet (July 2017)	Mondial	13.4	6602	58.42	Normal	73.7	High	15.01	Normal	144.37	High	8.82	Normal	14.53	High
	ruit (August 2017)		14	5403	135.49	High	36.4	Sli low	8.7	Low	84.04	Low	6.04	Normal	8.99	High

A comparison of CF outputs based on the formula developed from Year 1 was used. The degradation formula was based on constructing a baseline CF measurement at fruitlet (25-30 mm) stage and continuing measuring fruits with the PEA fluorimeter until the reduction was less than 50% of the baseline CF:

CF degradation=$\frac{(Fn-\sigma Fn)}{(F1-\sigma F1)}$<50%

Standard starch, firmness and °Brix readings were made for each pick date.

Fruits were harvested from each orchard samples at "CF pick" and "Starch pick" then half of the samples were treated with SmartFresh. Samples were stored in two regimes and locations for nine months:

5%CO_2: 1%O_2 (Control & +SF) at (Howt Green) (only CF pick samples).

5%CO_2: 1%O_2 (Control & +SF) at PQC (East Malling) (CF pick and starch pick samples).

Initial monitoring of fruit coming out of commercial stores (5%CO_2: 1%O_2) was in mid-April with subsequent assessments in Mid-May 2018.

Samples stored in the PQC were stored until mid-June 2018 then all samples were tested for CF, FDM, mineral analysis and quality assessments. Samples in May were sent for mineral analysis and FDM assessment to YARA analytic. Fruits were subject to CF measurements, fruit firmness, ^{o}Brix and acidity analysis at Landseer.

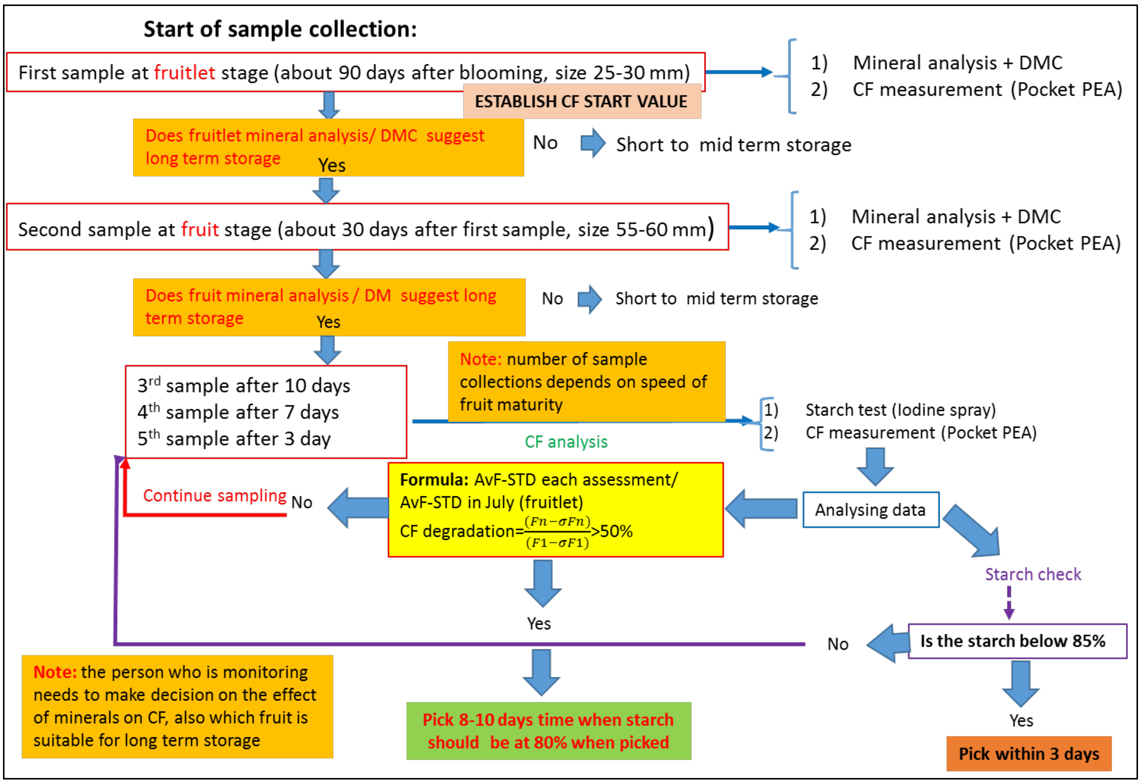


Figure 5.1. Decision tree flowchart for the process of sampling and analysing data for selecting the best orchards for long term storage and early warning for the best picking date.

Results

Work Package 1: Meta-analysis

Orchard surveys compiled by FAST have been collated on dry matter and mineral analysis from fruitlets, soil and leaves of 56 Gala orchards.

A preliminary multiple regression analysis was used to determine whether mineral content of soils influences fruit development and dry matter accumulation and, moreover, the extent to which mineral content of the soil influences leaflet and fruitlet analysis.

From the two years of available data (2015-2016) FDM variation across all the data sets ranged from 13.6% to 18.9% FDM.

The Gala dataset consisted of 56 measurements with a range from 13.8% to16.0% FDM. Additional mineral and leaf analysis for a subset of Gala orchards exist.

Pearson's Correlations of FDM against soil, leaf and fruit mineral analysis found a weak positive correlation of Fruit Dry Matter and Fe, K, Mg, P K:Ca ratio and a negative correlation with Zinc and Ca:N ratio. Calcium, Nitrogen, Copper, Manganese and Boron content of fruit did not influence the rate of FDM content in fruit. See Figures 6.1 and 6.2.

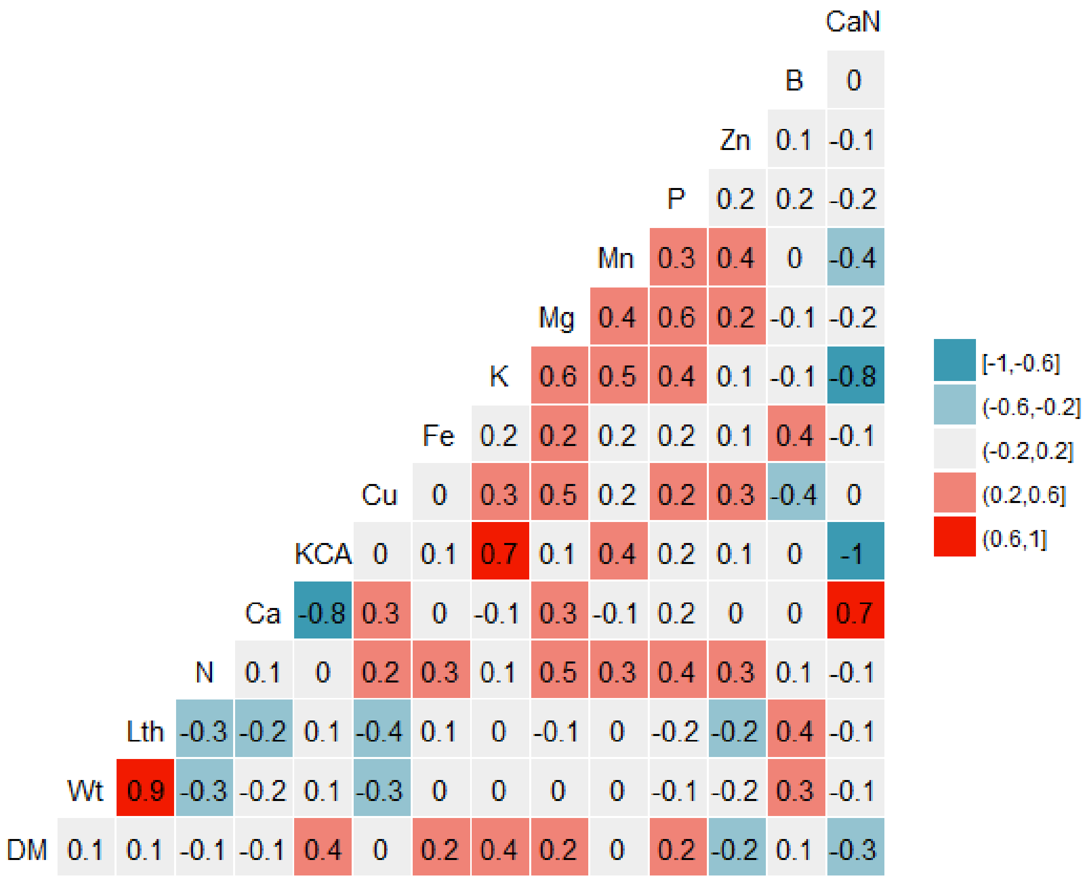


Figure 6.1. Pearson's correlation tests ($P<0.05$) of fruit mineral analysis and Fruit Dry Matter (DM) in Gala apples from 56 orchards over two seasons (2015-16, 2016-2017)

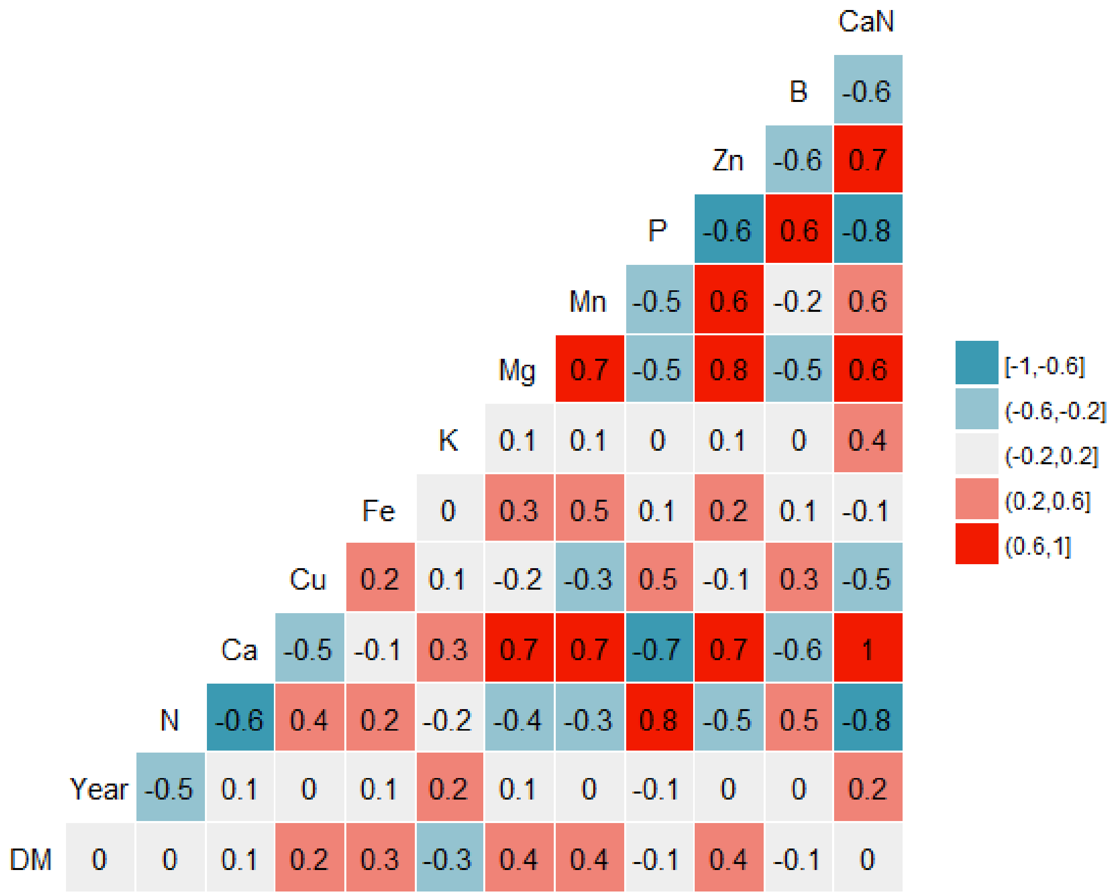


Figure 6.2. Pearson's correlation tests (P<0.05) of Leaf mineral analysis and Fruit Dry Matter (FDM) in Gala apples from 56 orchards over two seasons (2015-16, 2016-2017)

Mineral analysis of leaf samples in July of each sampling year has shown a weak positive correlation with leaf Cu, Fe, Mg, Mn and Zn and a negative relationship with K. Leaf calcium, Nitrogen, Phosphorus, Boron or the ratio of leaf Ca:N had no bearing on the amount of fruit dry matter content (DM). See Figure 6.3.

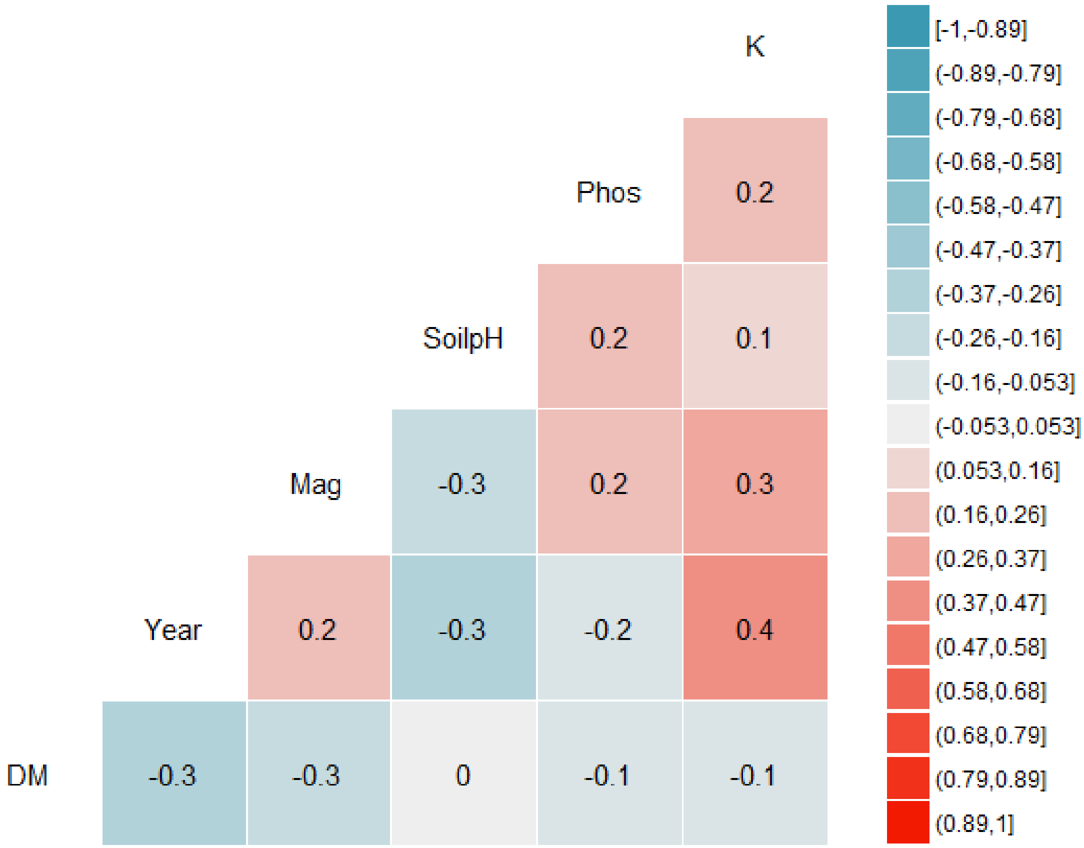


Figure 6.3. Pearson's correlation tests ($P<0.05$) of mineral analysis from soil samples and Fruit Dry Matter (DM) in Gala apples from 56 orchards over two seasons (2015-16, 2016-17).

With soil analysis, far fewer elements are measured, and a smaller number of samples were available compared to leaf and fruit analyses. Soil analysis data identified a weak negative correlation of Mg content in the soil and FDM. Soil pH and Phosphorous and Potassium content of soil samples had no bearing on FDM content.

Multiple regression analysis of fruit mineral content and FDM identified that there was a weak positive relationship between higher fruit potassium and magnesium and FDM and a negative relationship with Zinc, with higher fruit zinc content having lower FDM (Figure 6.4).

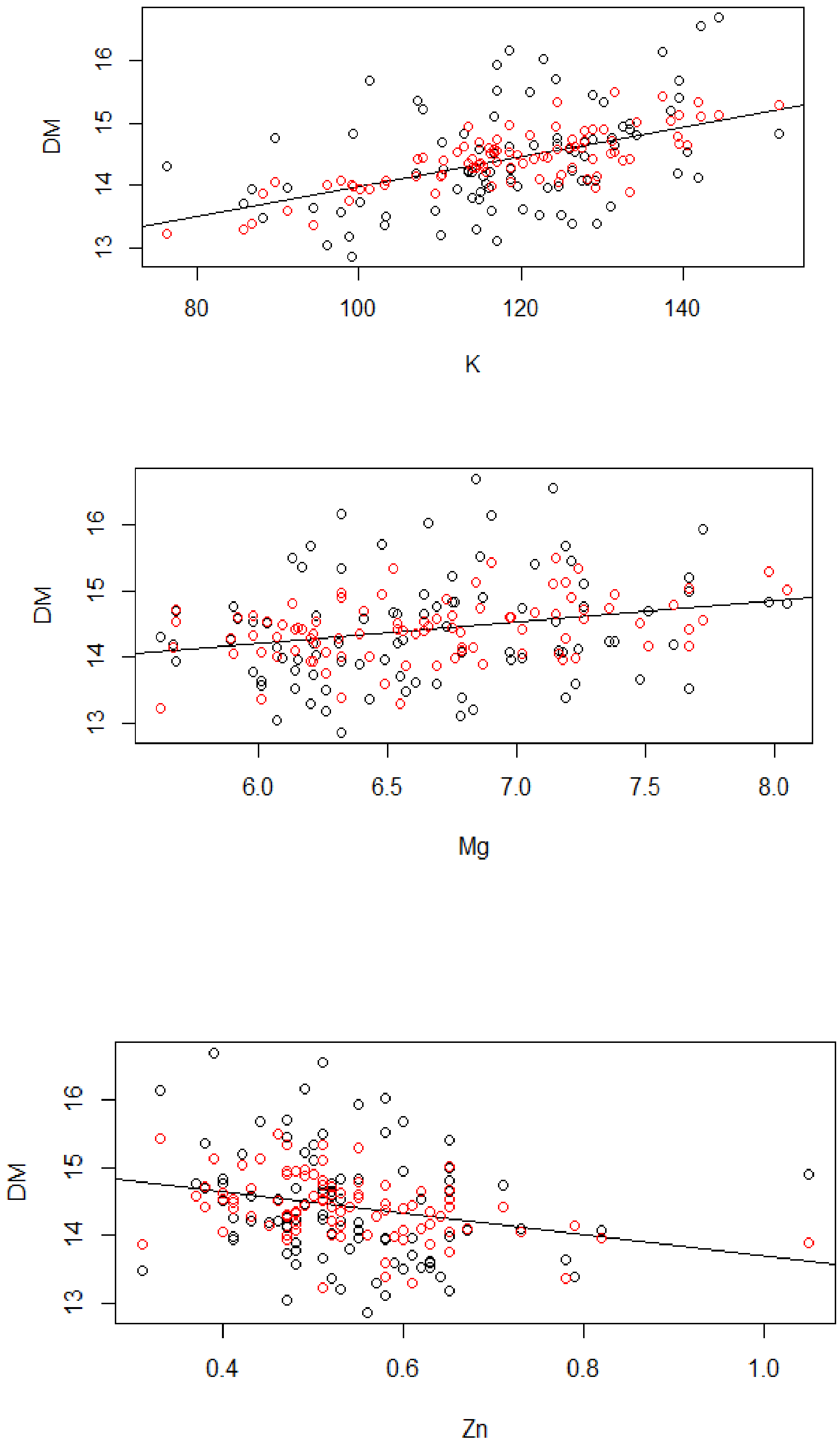


Figure 6.4. Multiple regression analysis depicting the positive relationship between K, Mg with fruit dry matter (DM) and a weak negative relationship with Zn. Concentration of mineral elements are in mg/100g FW.

Work Package 2: Pruning and reflective mulches

Five-year-old Gala grafted upon M9 trees pruned and trained as tall spindle (TS) were converted into centrifugal training system (CS) in February 2017. This resulted in the removal of most of the main fruiting branches, resulting in a decrease in the yield potential for the next two to three years. Consequently, the results presented in this report need to be taken with caution as this is the first year after the treatments have been applied to the trees. The reflective covers (REFL) were applied at fruit set. The canopy microclimate assessments have been performed during the season and the fruits were harvested on the 5th of September 2017.

Effect of the treatments on the canopy microclimate

The primary role of the treatments was to generate a range of light levels intercepted by the canopy and fruits during the growing season. To measure light penetration through the canopy, the tree has been divided in three canopy zones - upper, middle, and lower. The AccuPAR readings were taken during the morning and the afternoon of 14, 15, 24 and 25th August, giving sixty-five readings per treatment. The AccuPAR readings are expressed as a percentage of the external PAR to compensate for temporal variations in light intensity.

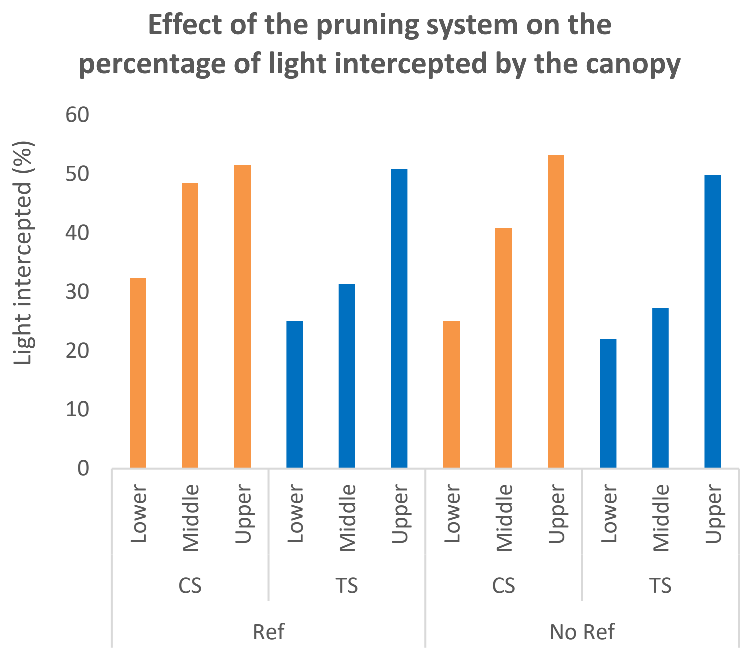


Figure 7.1. Effect of pruning system on the % of light intercepted by the canopy at three different heights of the canopy. Ref = Reflective cover, No Ref = No reflective cover, TS = Tall Spindle, CS = Centrifugal System.

The pruning system effects the percentage light penetration with the CS system intercepting an average 41.5% of the external light, compared with 34.4% for TS. These results are preliminary and to be confirmed in the next years when the trees will be more comparable between the two systems. The results are, however, consistent with observations in other studies in which the CS pruning system has been reported as beneficial to light interception. Within the tree, there is a gradient of light from the top to the bottom of the tree, with the upper part of the tree intercepting between 49% and 53% of the external light, the bottom between 32 and 25% of the light. See Figure 7.1.

For all the treatments and location in the tree, the reflective covers had a positive effect on the percentage of light intercepted by the canopy. This resulted in an increase of the fruit temperature, measured at the same time as light by thermal imaging (data not shown).

Effect of the treatments on yield and grading

The suppression of most of the branches at pruning time resulted in a reduction of yield for the CS treatments with an average yield of 45 kg compared to an average 61 kg for TS (Figure 7.2). It is expected that the respective yield will become more comparable in the next three years. The reduction in yield in CS is lower than expected after pruning.

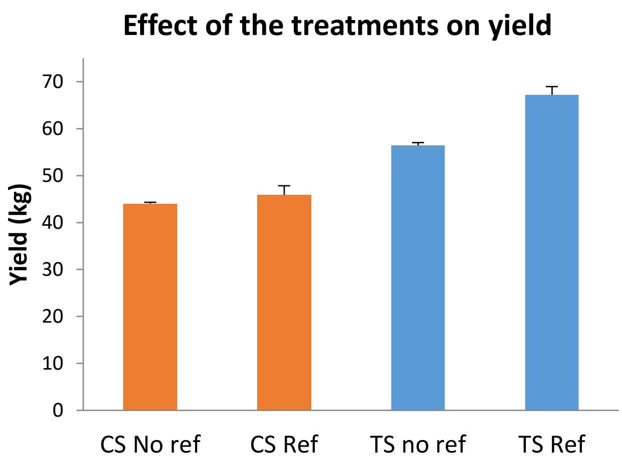


Figure 7.2 Effect of the training system (Centrifugal (CS) in orange and Tall spindle (TS) in blue) with or without reflective mulches on total yield.

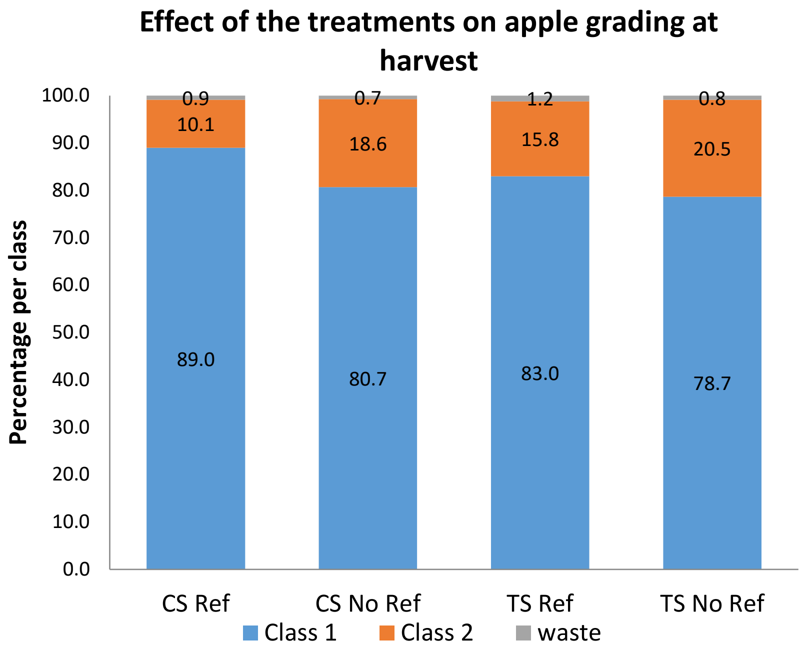


Figure 7.3 Effect of the treatments on apple grading, in percentage of total yield for each category. CS Ref = Centrifugal system with reflective cover, CS No Ref = Centrifugal system no reflective cover, TS Ref = Tall Spindle with reflective cover, TS No Ref = Tall spindle no reflective cover.

The application of reflective covers at fruit set did increase yield in both treatments by 5 (CS) and 19% (TS). This increase in yield is encouraging regarding the effects of light on apple production and highlights the dramatic effect that light levels can have on apple production under the UK climate. These differences in yield will have an impact on the quality assessments and need to be confirmed in the next years before drawing any definitive conclusion.

The treatments also had some effects on the grade of the apple fruits at harvest (Figure 7.3).

Waste was low for all treatments, representing between 0.7 and 1.2% of the harvested crop. The Class 1 apples represented on average 84.5% (CS) and 80.9% (TS); Class 2 fruits 14.4% (CS) and 18.2% (TS). The reflective covers did increase the proportion of Class 1 fruits in both pruning systems with an increase by 10% for CS and 5% for TS. Whilst the increased Class 1 to Class 2 ratio observed with CS could be explained by a lower yield in comparison to TS, the reflective mulch had a positive effect on both yield and grading of the crop for both pruning systems.

Harvest Analysis- NRI

Apples from the top and bottom of the trees under reflective covers and pruning regimes were harvested on 20 September and transferred to the Produce Quality Centre (PQC) where fruits were sampled for dry matter content and assessed non-destructively for FDM content using a Felix 750.

The apples harvested from the higher canopy (>1.5 m) of TS trees were on average 0.6-0.8% higher in FDM, but just failed to reach significance. However, the °Brix of juice samples was significantly higher in fruits from the upper canopy. Tall Spindle tree apples harvested in the absence of reflective mulches fruits from the upper canopy averaged 12 °Brix compared to 11.4 °Brix from fruits from the lower canopy (<0.6M). In CS pruned trees, the % FDM in fruits from the upper canopy averaged 13.5% compared to 12.7% in the lower canopy. With centrifugally pruned trees, FDM content was highest in the upper canopy fruit (12.9% FDM) compared to 12.4% in the lower canopy.

The incorporation of reflective covers failed to elevate the percentage of FDM in conventional Tall Spindle trees. In the centrifugal trees reflective covers yielded fruit with 13.5% FDM in the upper canopy compared to 12.9% FDM where no reflective covers were used, but the difference was not statistically significant. No increase in °Brix was observed in apples grown under reflective covers in centrifugally pruned trees (Figures 7.4 and 7.5).

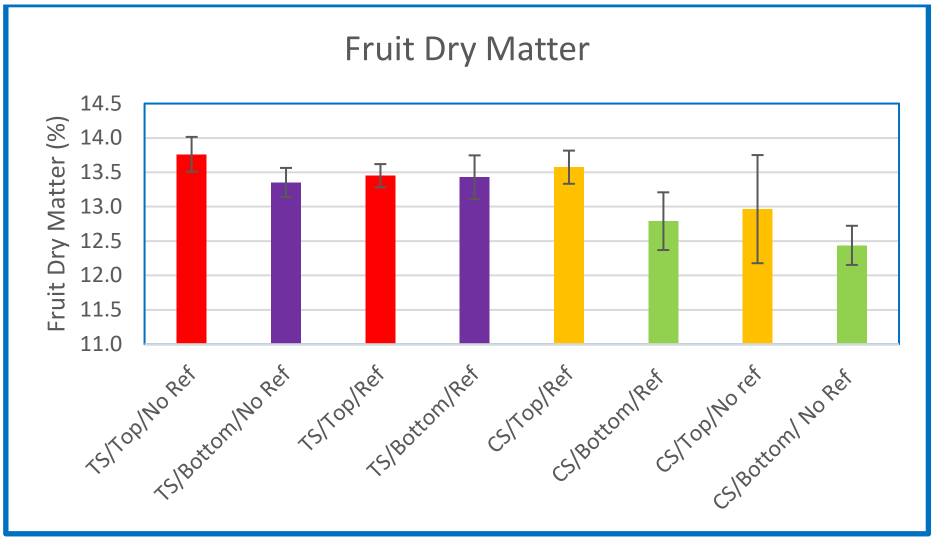


Figure 7.4. The % FDM of Gala apples grown under conventional Tall Spindle (TS) or Centrifugal Pruning systems (CS) harvested from the top (1.5 m) or bottom (0.6 m) canopy. Trees were grown under the presence (Ref) or absence (No Ref) of reflective covers.

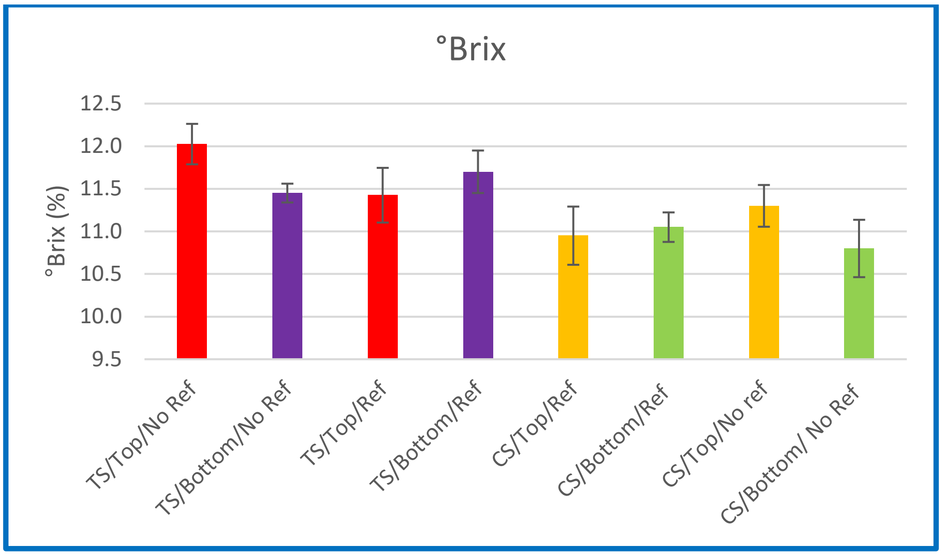


Figure 7.5. The °Brix of Gala apples grown under conventional Tall Spindle (TS) or Centrifugal Pruning systems (CS) harvested from the top (1.5 m) or bottom (0.6 m) canopy. Trees were grown under the presence (Ref) or absence (No Ref) of reflective covers.

The bulk of the remaining fruit was randomised within their orchard treatments, while damage, diseased and misshapen fruits were discarded. Fruits were stored in 3% CO_2, 1% O_2 (0.5-1.0 °C) for 5 months, after which fruits were assessed immediately ex-store and again after 7 days at 18°C.

The full interaction of pruning treatments, reflective mulches and tree position of harvested fruits were not significant ($P<0.05$) and are not reported on. However, several differences between overall means and individual two-way interactions were significant ($P<0.05$).

Fruits located on the top of the tree produced apples firmer than at the bottom and (Table 3.1) this effect was most pronounced on centrifugally pruned trees. As expected, ex-store fruit was firmer than fruit assessed after seven days shelf-life (18°C) and fruit from conventional tall spindle trees were firmest. Fruit under reflective covers were slightly softer than fruits where no covers were used.

Table 3.1. The impact of pruning systems (Tall spindle versus Centrifugal training) and the presence of reflective covers on the firmness (N) of Gala stored for 5 months at 3% CO_2, 1% O_2 at 0.5-1.0°C. Overall means.

Fruit Position	Top (>1.5M)	Bottom (0.6 M)	P value
	63.7	62.2	0.018
	$LSD_{0.05}$ 1.151		
Assessment	**Ex-store**	**Shelf-life**	
	64.5	61.4	<0.01
	$LSD_{0.05}$ 1.151		
Fruit Position	**Bottom (0.6 M)**	**Top (>1.5 M)**	
Centrifugal	61.7	**64.3**	0.049
Tall Spindle	62.8	63.1	
	$LSD_{0.05}$ 1.627		
Assessment	**Ex-store**	**Shelf-life**	
Centrifugal	63.8	62.1	0.022
Tall Spindle	**65.1**	60.7	
	$LSD_{0.05}$ 1.627		
Assessment	**Ex-store**	**Shelf-life**	
No covers	**65.5**	61.1	0.027
Reflective covers	63.5	61.7	
	$LSD_{0.05}$1.627		

Figures in bold are significantly different (P<0.05) from data in opposing column.

The overall effect of fruit grown under different pruning and reflective mulches on the retention of °Brix in fruit, found that apples sampled from the top of the tree canopy higher in °Brix than fruit sampled lower down the tree. Tall spindle trees were higher in Year 1 of the centrifugal tree conversion (Table 3.2).

Table 3.2. The impact of pruning systems (Tall spindle versus Centrifugal training) and the presence of reflective covers on the °Brix of Gala stored for 5 months at 3% CO_2, 1% O_2 at 0.5-1.0°C. Overall means.

Pruning	Tall Spindle	Centrifugal	$LSD_{0.05}$
	11.7	11.10	0.271 (P<0.01)
Fruit Position	**Top**	**Bottom**	
	11.6	11.2	0.383 (P=0.016)
Assessment	**Ex-store**	**Shelf-life**	
	11.6	11.3	0.271 (P=0.043)

Figures in bold are significantly different (P<0.05) from data in opposing column.

Interestingly, the use of reflective covers reduced the incidence of rotting in stored fruit. This effect was most pronounced in fruit harvested from the upper canopy where fruit grown under reflective covers recorded an incidence of 1.2% rots, compared to 10% rots in fruits from the upper canopy where no covers were in place (Table 3.3). This may be a result of reducing the amount of inoculum on the orchard floor that is redirected into the canopy during heavy rain. However, the highest incidence of rots was in the upper canopy suggesting other temperature/UV effects may be influencing the incidence of rotting.

Table 3.3. The impact of pruning systems (Tall spindle versus Centrifugal training) and the presence of reflective mulches on the % rotting of Gala stored for five months at 3% CO_2, 1% O_2 at 0.5-1.0°C. Overall means.

% Rotting	Reflective Covers	No Covers
Overall	**3.1**	8.1
$LSD_{0.05}$ (P=0.048)	*4.96*	
Position		
Top	**1.2**	10.0
Bottom	5.0	6.2
$LSD_{0.05}$ (P=0.048)	*7.10*	

Figures in bold are significantly different (P<0.05) from data in opposing column.

Work package 3: Thinning Methods

Bud stage monitoring for treatment events commenced in March 2017. Treatment 2 Bud Extinction was carried out on 24 March (BBCH 54, mouse ear). Treatment 3 Mechanical Thinning was carried out on 19 April at full bloom (BBCH 65, 60% flowers open and first petals falling). The chronology is presented in Appendix 2 WP 3.

Fruit size assessments for chemical and hand thinning treatment events were commenced in May 2017. Treatments 4 and 5 (chemicals Exilis and Brevis) were applied on 23 May (BBCH 71, fruit size 12mm). Day and night temperatures plus light were monitored and forecasts consulted to ensure optimum conditions before, at and after application (Table 4.1).

Table 4.1. Day and night temperature and light before, at and after chemical application events (23 May 2018).

	AIR TEMPERATURE ºC				LIGHT w/m2
	DAY		NIGHT		TOTAL
	MAX	MIN	MAX	MIN	DAILY
18/05/2017	17.2	9.4	10.8	7.8	8597
19/05/2017	16.1	8.9	10.2	5.6	10950
20/05/2017	17.5	6.5	11.6	6.5	19599
21/05/2017	21.5	7.5	13.6	7.2	24603
22/05/2017	25.2	10	15.7	9.8	20704
23/05/2017	24.6	12	18.1	11.5	17726
24/05/2017	27.7	13.2	18.6	8.6	23629
25/05/2017	25.9	11.9	15.8	6.9	26091
26/05/2017	26.4	9.8	18.6	9.8	26789
27/05/2017	26	17.4	16.8	9.3	22379
28/05/2017	25.9	11.2	17.7	11.9	18094

Treatment 6 Hand Thinning Standard was carried out on 3 June (BBCH 72, fruit size 21mm). Treatment 7 Hand Thinning Size was carried out on 15 June (BBCH 73, fruit size 30mm) and 3 July (BBCH 74, fruit size 40mm). Treatment 8 was carried out on 30 June (BBCH 74, fruit size 40mm).

Second fruit fall commenced around 2 June and continued until around 29 June.

Leaves for mineral analysis were collected on 26 April when N levels were found to be within normal limits.

Temperature monitoring in the orchard commenced in spring. Below zero values were recorded on 18, 19, 20, 25 and 27 April plus on 10 May during full bloom and at early fruitlet.

Many flowers were seen to have fallen and there was significant damage to fruitlets in the lower half of the tree canopy below 1.5m noted on 27 April. First fruit fall was minimal (Appendix 2 WP 3 Chronology).

Fallen fruit was collected for counting on 2, 6 and 29 June. The number, average and total amount of fruit fallen and removed was calculated (Table 4.2 and Figure 8.1).

Due to second fruit fall coinciding with fruit falling due to chemical treatments it was not possible to separately determine the amounts for different methods/causes. However, the percentage of total fruit fallen/removed per treatment was calculated (Figure 8.2).

There were no significant effects of treatment on natural fruit fall or total fruit fall/removal except for hand thinning Treatments 6, 7 and 8.

There were statistically significant differences between Treatments 6, 7 and 8 of fruit naturally dropped and fruit removed by hand thinning (Figure 8.3). Treatment 7 Hand Thinning to Size had significantly fewer fruit removed by hand thinning than Treatments 6 or 8. Treatments 6 and 8 had significantly fewer fruit fallen naturally compared to Treatment 7.

Table 4.2. Average and total number of Fruit Fallen and Removed per Treatment (via fruit drop and thinning combined).

Treatment	Mean fruit number	Total fruit number
1	115.0	460
2	103.8	415
3	100.3	401
4	161.5	646
5	237.0	948
6	187.3	749
7	158.0	632
8	155.0	620.0

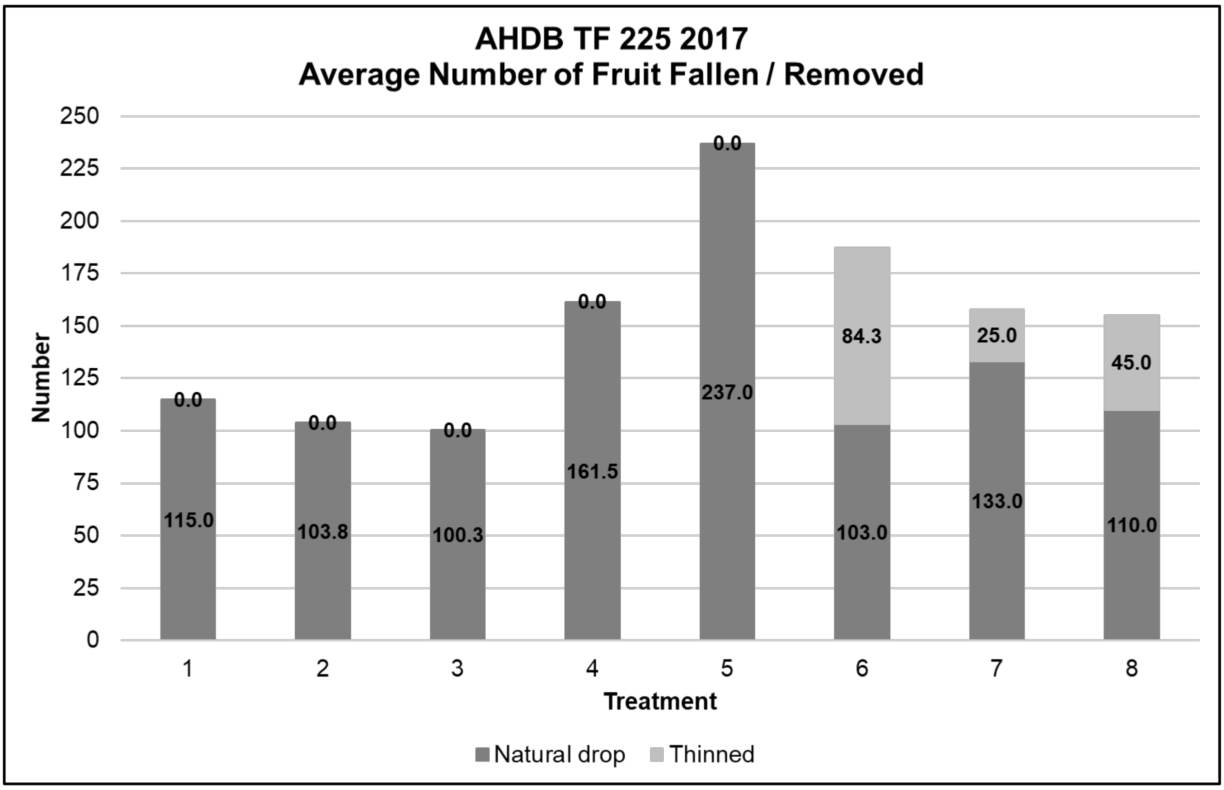


Figure 8.1. Average Number of Fruit Fallen and Removed. No significant effects.

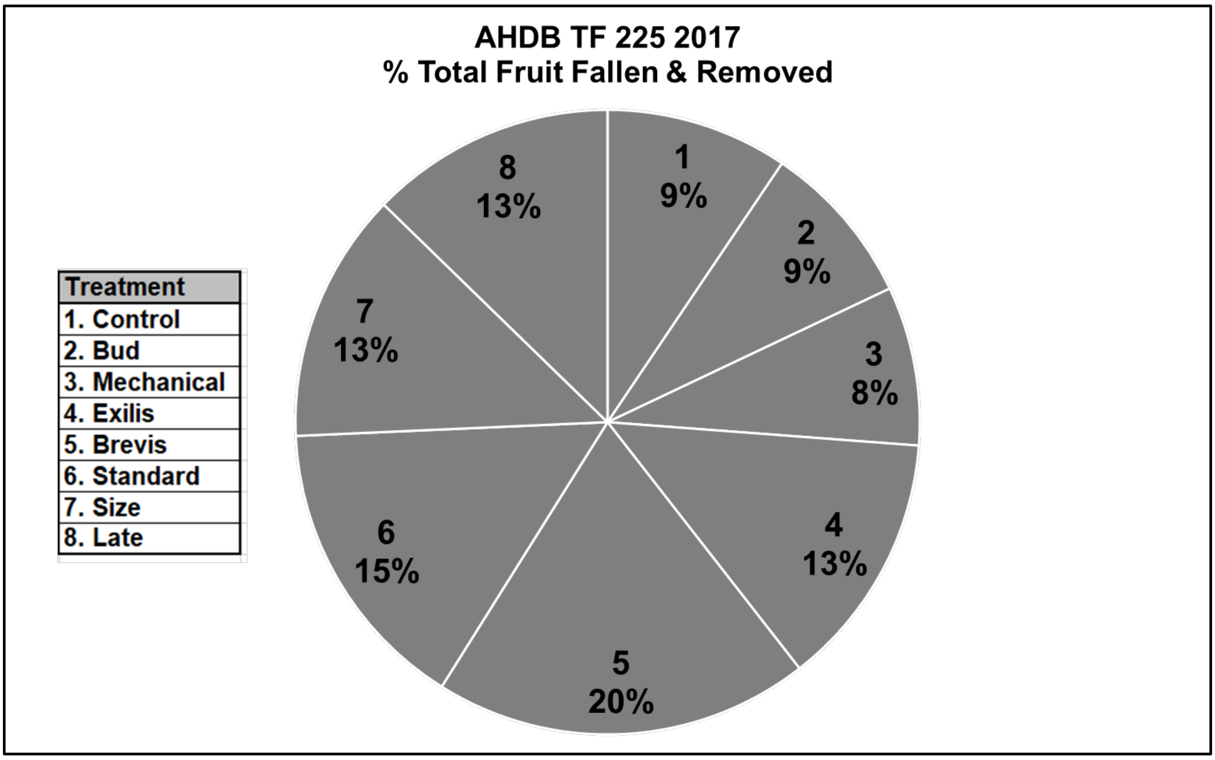
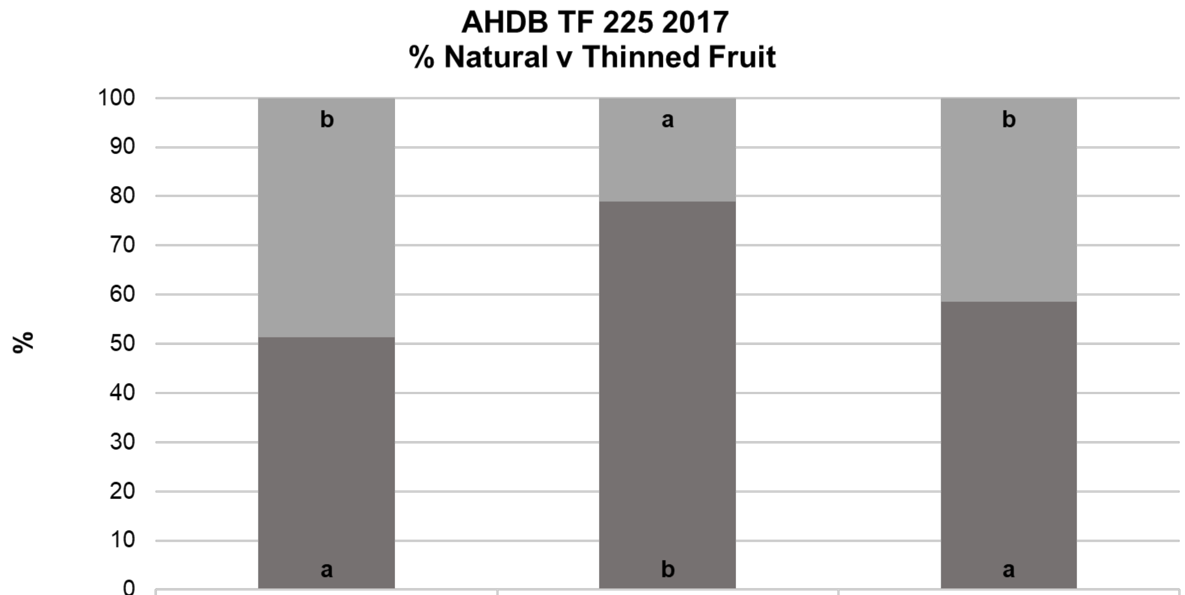


Figure 8.2. Percentage Total Fruit Fallen and Removed.



	6	7	8
Thinned %	48.60	21.12	41.51
Natural %	51.40	78.88	58.49

Figure 8.3. Percentage Natural v Thinned Fruit (hand thinned treatments only). Results with different letters are significantly different from one another. P value < 0.0001.

Starch tests for harvest prediction were carried out on 4, 11 and 14 September when values were 89.7%, 88.6% and 86% respectively. Pressure was also carried out on 11 and 14 September when results were 8.8kg and 8.6kg. °Brix on 14 September was 12%.

Fruit mineral analysis was carried out on 12 September and a pick date of 18 September recommended based on laboratory storage predictions.

Fruit was harvested on 20 September. Total yields per treatment and average per tree in kg were calculated plus average total yield T/ha and Class 1 yields T/ha (Table 4.3).

There were no significant effects of treatment upon yield. Treatments 1, 7 and 5 had the highest average total yield T/ha and Treatments 8, 6 and 2 the lowest. However, Treatments 7, 4 and 3 had the highest average Class 1 yield T/ha and Treatments 6, 5 and 8 the lowest (Figures 8.4, 8.5 and 8.6).

Table 4.3. Yields summary – total yield per treatment kg, average total per tree kg, average total T/Ha and average Class 1 T/Ha.

TREATMENT	TOTAL YIELD PER TREATMENT KG (C1 & Waste)	AVERAGE TOTAL YIELD PER TREE KG (C1 & Waste)	AVERAGE TOTAL YIELD T/HA (C1 & Waste)	AVERAGE CLASS 1 T/HA
1	261.3	21.8	62.2	33.5
2	233.1	19.4	55.5	33.6
3	235.0	19.6	55.9	34.7
4	222.9	20.3	58.0	35.3
5	255.9	21.3	60.9	29.6
6	230.8	19.2	55.0	28.8
7	260.4	21.7	62.0	36.2
8	215.3	17.9	51.3	29.7

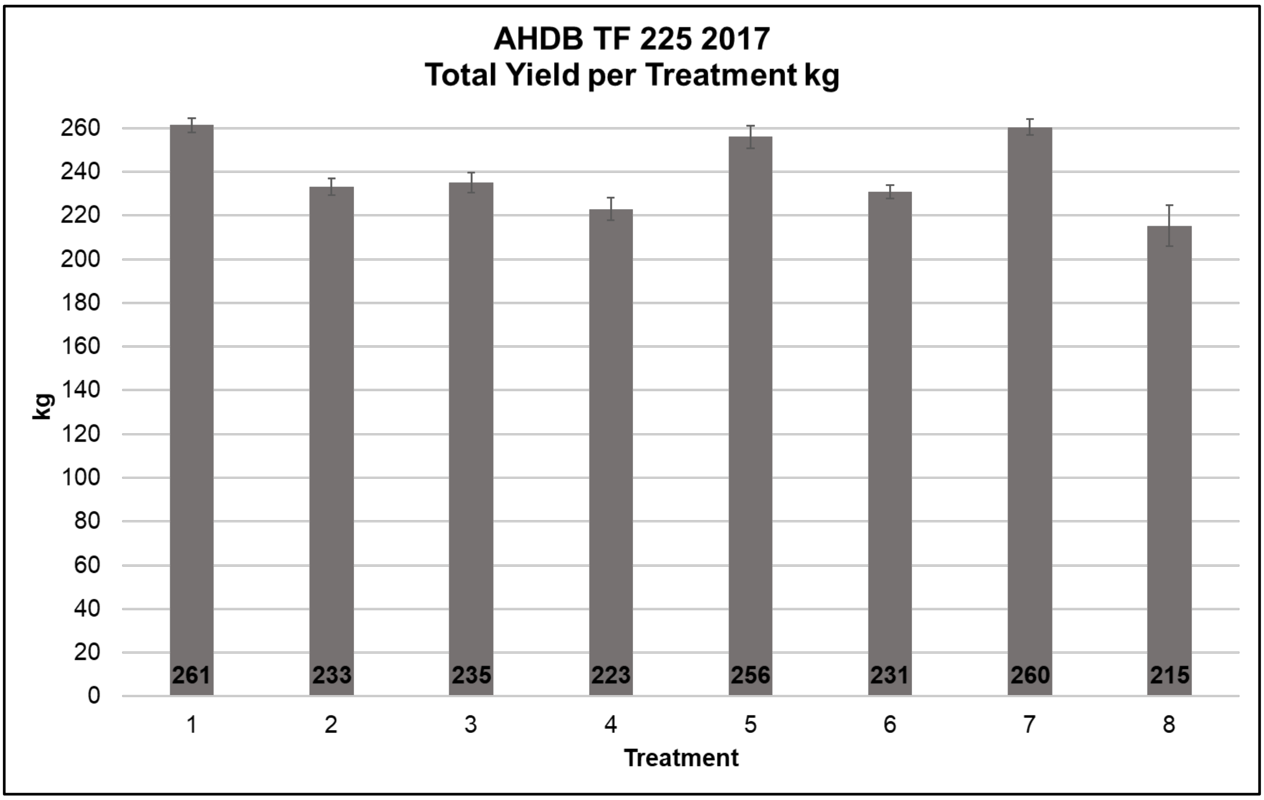


Figure 8.4. Total yield per treatment kg. No significant effects of treatments (P value 0.6400).

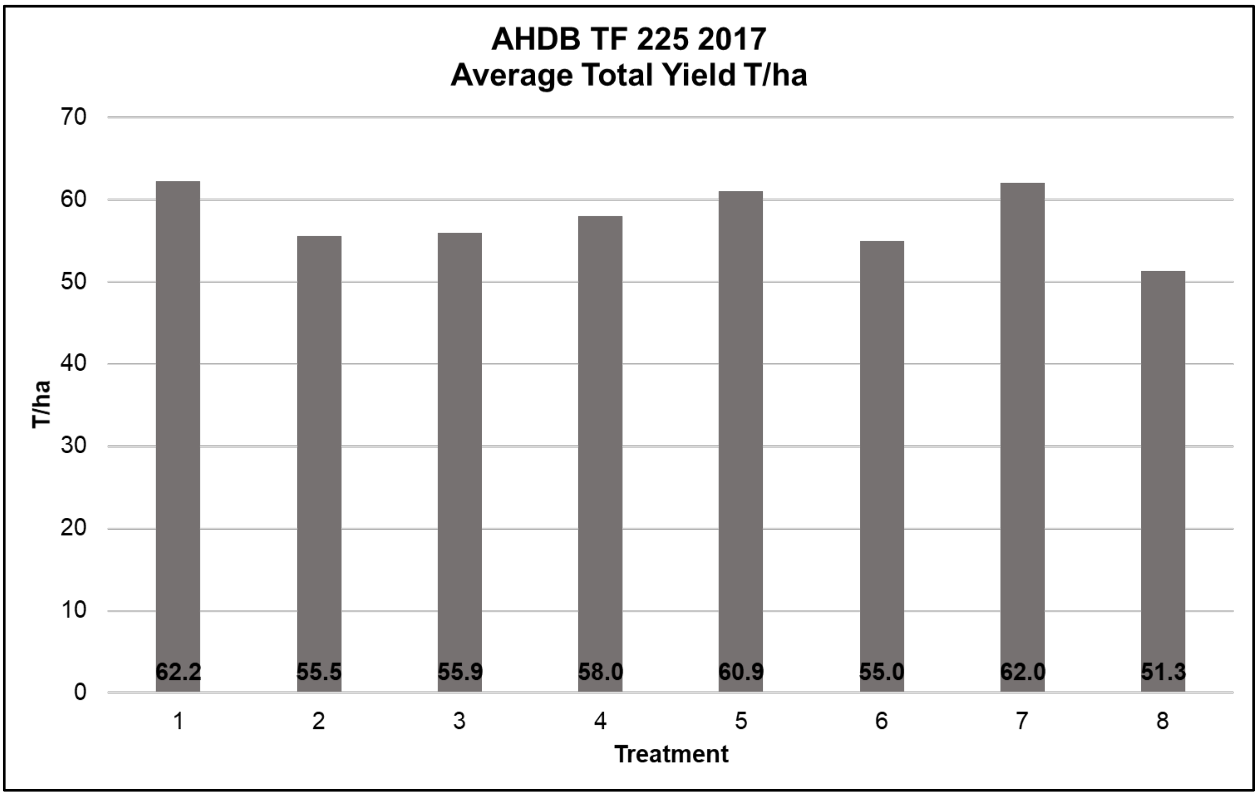


Figure 8.5. Average Total Yield per Treatment T/Ha (includes Class 1 and Waste). No significant differences (P value 0.6588).

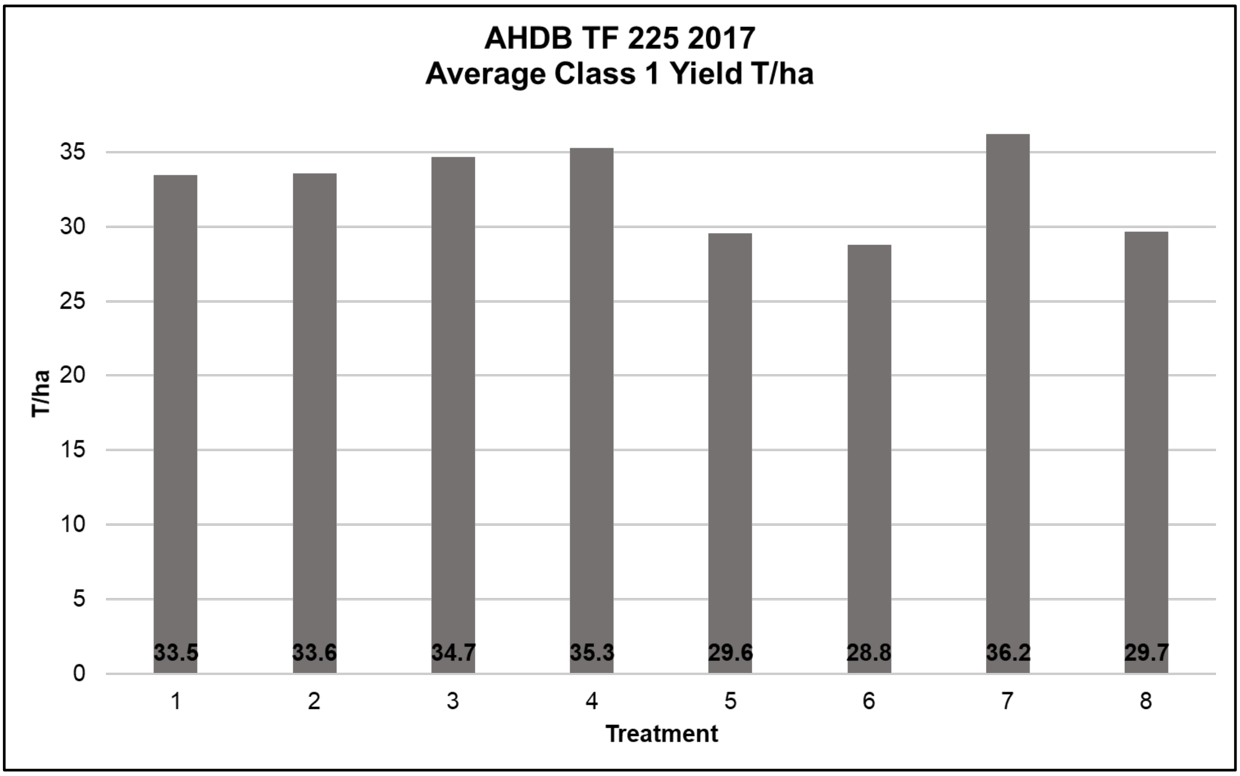


Figure 8.6. Average Class 1 Yield per Treatment T/ha. No significant differences (P value 0.3306).

Fruit sampling for maturity assessments was carried out on 19 September and fruit was processed on 20 September. Fruit quality assessments commenced in October.

There were no significant effects of treatment on fruit quality (grade out) when the 60 fruit per treatment plot sampled at harvest were assessed. Treatment 2, 3, and 4 had the highest Class 1 percentages and 5, 6 and 8 the lowest (Figure 8.7).

There were no significant effects of treatment on waste categories except for lack of % Red. Treatment 8 had significantly fewer fruit lacking colour compared to Treatments 3, 4, 5 and 6. Treatment 3 had the highest numbers of fruit with poor colour. Frost damage and small fruit accounted for most of the other Waste in 2017. Treatment 8 had the most damaged fruit and 6 the least. However, Treatment 6 had the most misshaped fruit and Treatment 3 the least. Treatment 1 had the most small fruit and Treatment 3 the least. But Treatment 3 had the most diseased fruit and 6, 7 and 8 no diseased fruit. Treatment 6 had the most fruit with other defects (mostly oversize fruit > 80mm) and Treatments 4 and 5 had none (Figure 8.8).

There were no significant effects of treatment upon average fruit weight. Average fruit weight was between 110g and 130g and all treatments' fruit weight reached the minimum industry standard (110g). Treatments 8, 7 and 2 had the highest average fruit weight and 1, 4 and 5 the lowest (Figure 8.9).

There were no significant effects of treatment upon size distribution. Over 50% of the Class 1 fruit assessed were between 60mm and 70mm except for Treatment 7. Treatment 1 had the most fruit 55-60mm and Treatment 8 the least. Treatment 5 had the most fruit 60-65mm and Treatment 8 the least. Treatment 8 had the most fruit 65-70mm and Treatment 5 the least. Treatment 7 had the most fruit 70-75mm and Treatment 1 the least. Treatment 6 had the most fruit 75-80mm and Treatment 1 had none (Figure 8.10).

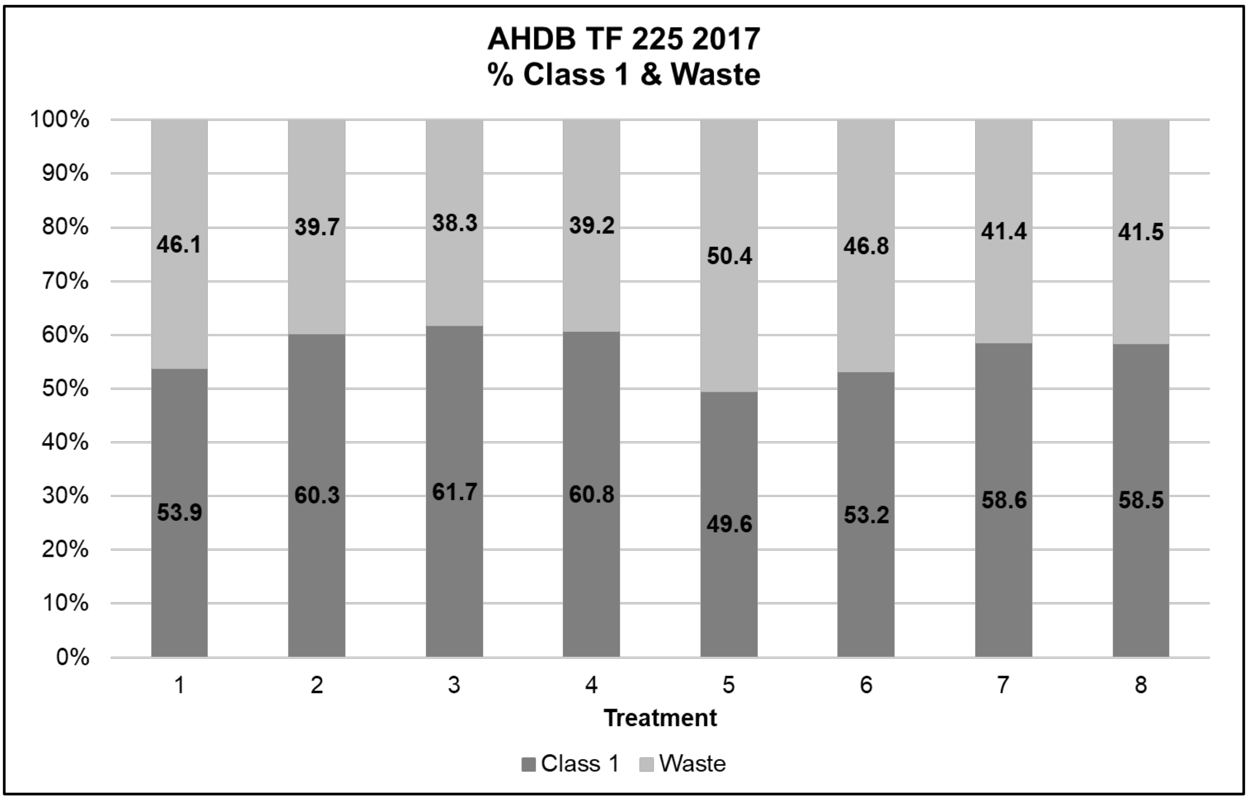
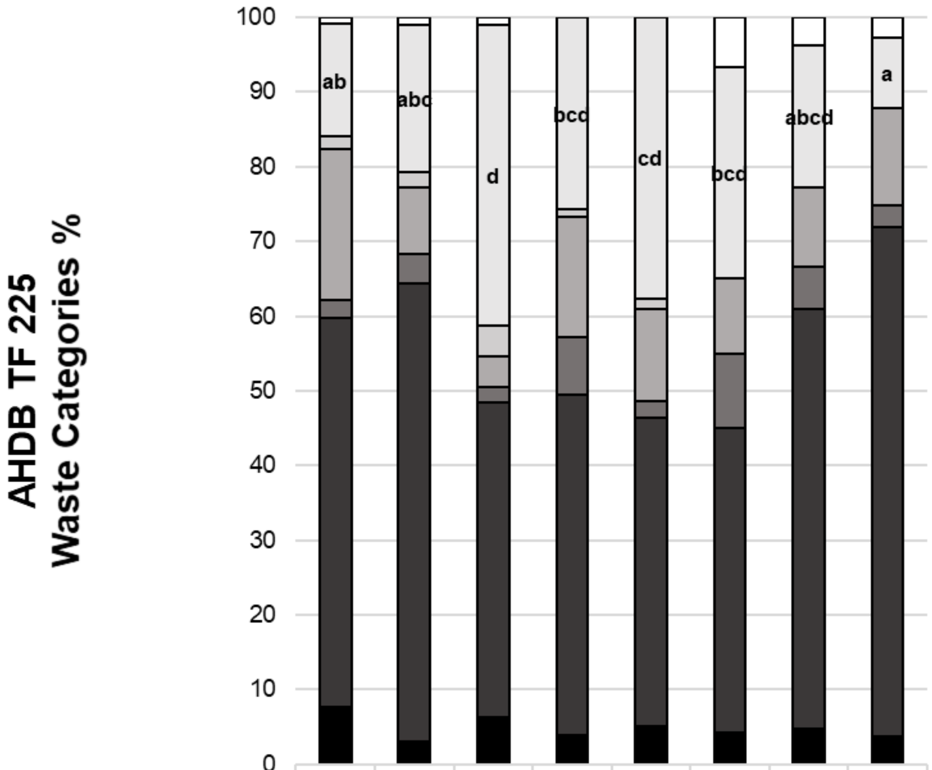


Figure 8.7. Percentage class by weight. No significant effects (Class 1 P value = 0.1599, Waste P value = 0.1603).



	1	2	3	4	5	6	7	8
Other	0.8	1.0	1.0	0.0	0.0	6.7	3.8	2.8
Lack % Red	15.1	19.8	40.2	25.7	37.7	28.3	19.0	9.3
Diseased	1.7	2.0	4.1	1.0	1.4	0.0	0.0	0.0
Small	20.2	8.9	4.1	16.2	12.3	10.0	10.5	13.1
Mis-Shape	2.5	4.0	2.1	7.6	2.2	10.0	5.7	2.8
Damage - pest/physical	52.1	61.4	42.3	45.7	41.3	40.8	56.2	68.2
Scarring/Russet	7.6	3.0	6.2	3.8	5.1	4.2	4.8	3.7

Treatment

Figure 8.8. Waste categories %. Significant effects of treatment were noted for Lack of % Red (P value 0.0167). There were no significant effects of treatment for Scarring/Russet (P value 0.9962), Damage (P value 0.0855), Mis-Shape (P value 0.2083), Small (P value 0.8211), Diseased (P value 0.1191) or Other (P value 0.631).

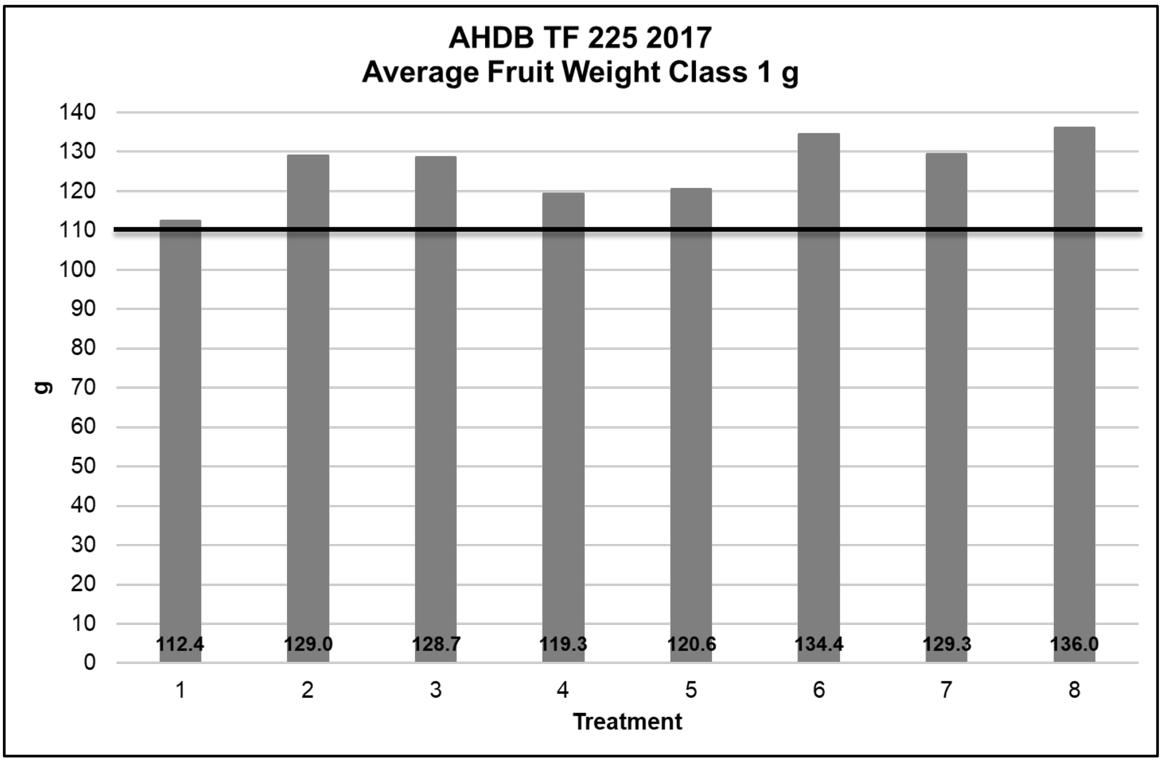
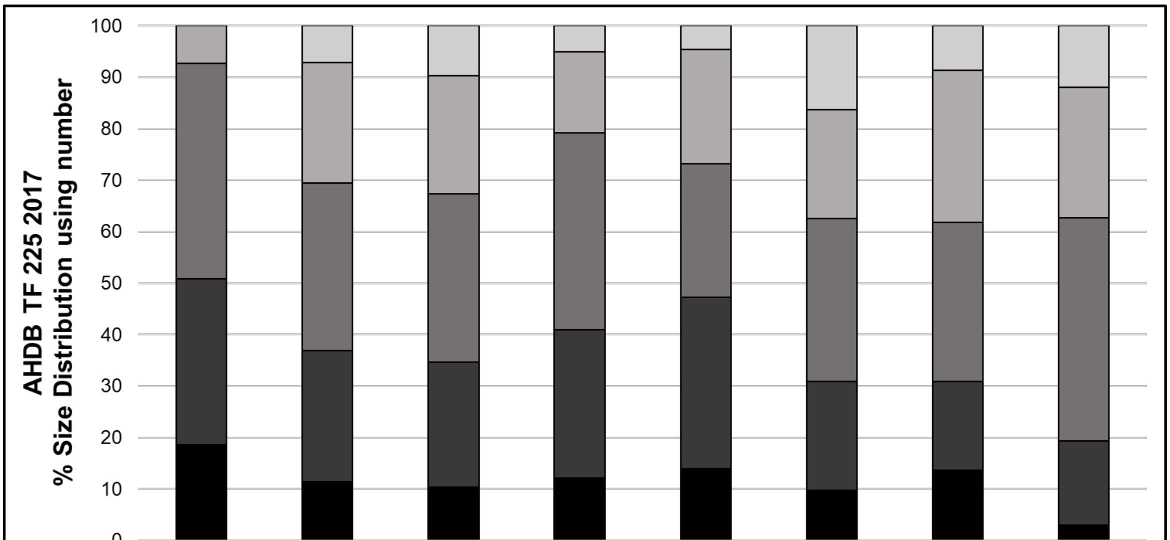


Figure 8.9. Average fruit weight Class 1. No significant effects (P value 0.2071). Black line denotes minimum industry standard weight required.



	1	2	3	4	5	6	7	8
75-80	0.0	7.1	9.7	5.0	4.6	16.3	8.6	11.9
70-75	7.3	23.4	22.9	15.8	22.2	21.1	29.5	25.4
65-70	41.9	32.6	32.6	38.1	25.9	31.7	30.9	43.3
60-65	32.3	25.5	24.3	28.8	33.3	21.1	17.3	16.4
55-60	18.5	11.3	10.4	12.2	13.9	9.8	13.7	3.0

Figure 8.10. Percentage size distribution using number of fruit. No significant effects (P values = 55-60mm 0.2022, 60-65mm 0.5408, 65-70mm 0.0717, 70-75mm 0.2098, 75-80mm 0.4413).

There were no statistically significant effects of treatments on starch. The optimum starch of 80% at harvest was reached for all treatments except Treatment 6 (Figure 8.11).

There were statistical effects of treatments on °Brix where Treatment 8 Hand Thinning Late had significantly higher °Brix than all other treatments. Only treatments 5, 7 and 8 reached the optimum °Brix of 12 at harvest (Figure 8.12).

There were statistical effects of treatments on fruit firmness where Treatment 3 (Mechanical Thinning) had significantly lower pressure than all other treatments except Treatment 2 (Bud Thinning). The optimum pressure of 8kg/m^2 at harvest was reached by all treatments (Figure 3.18).

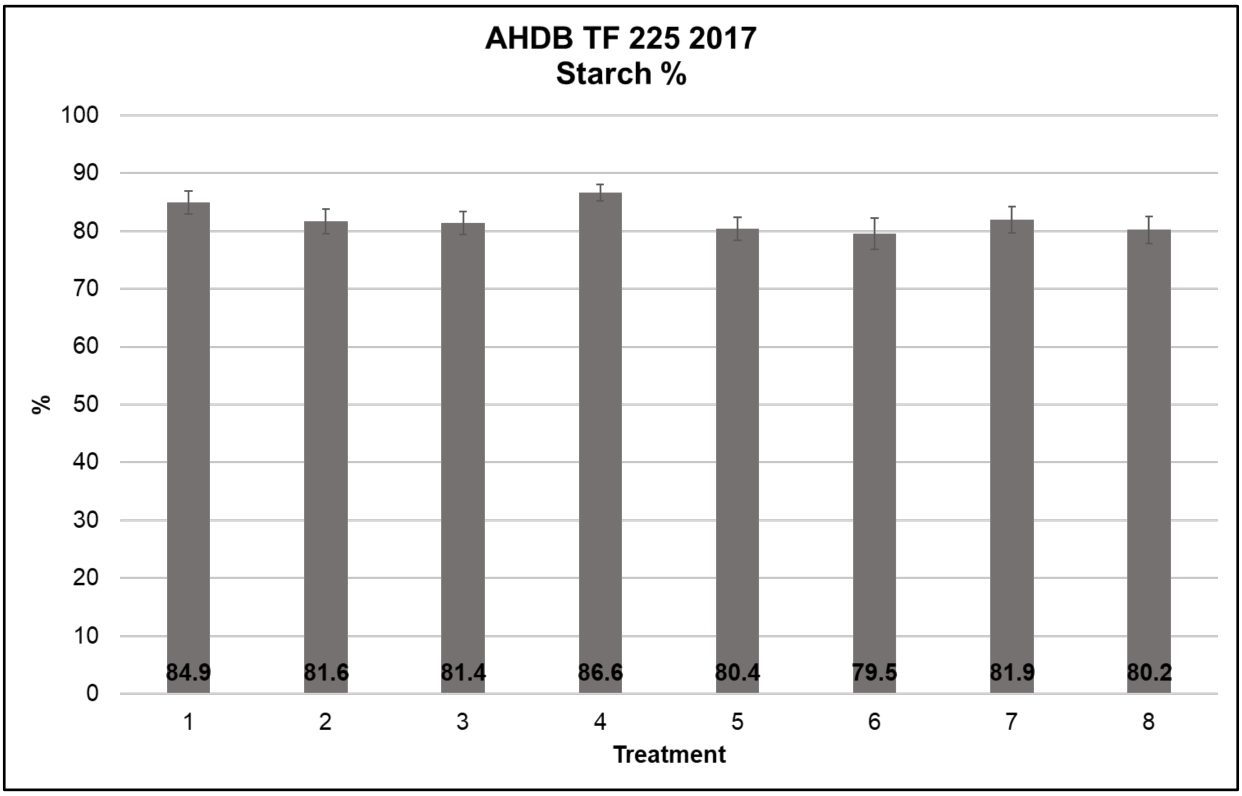


Figure 8.11. Percentage starch from fruit sampled at harvest. No significant effects (P value 0.2509).

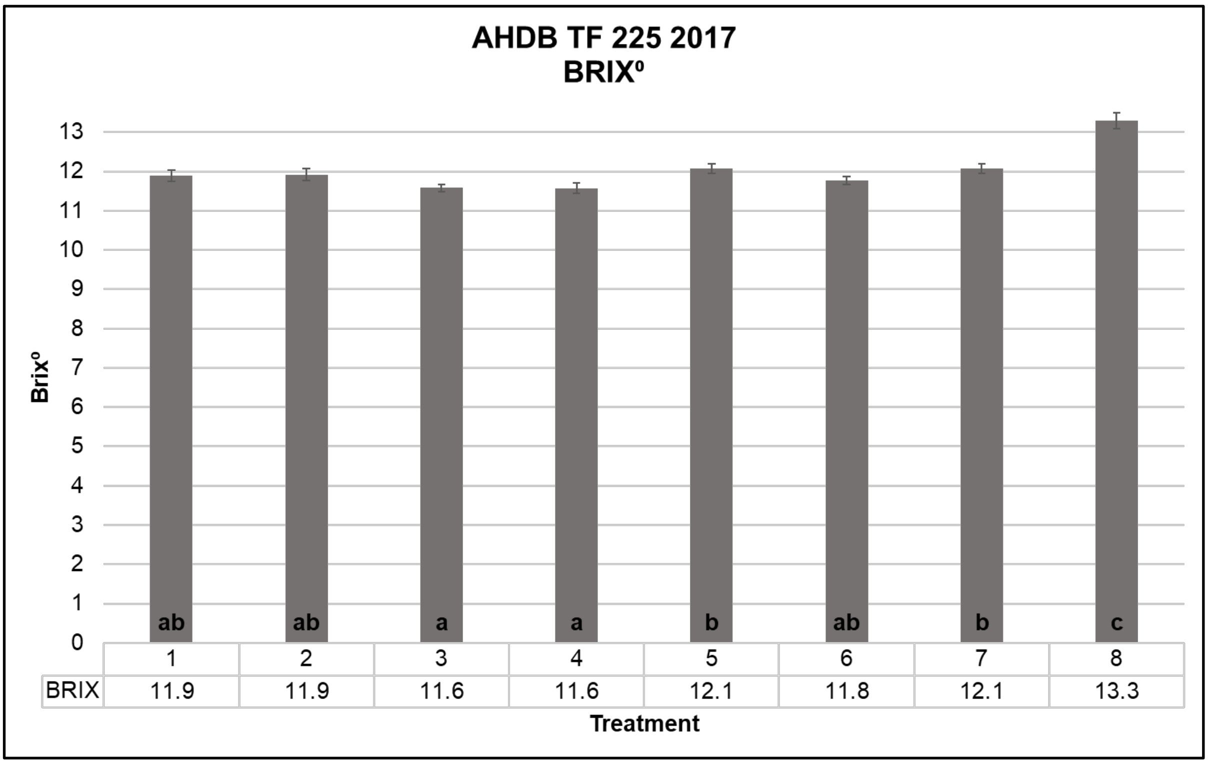


Figure 8.12. °Brix of fruit measured at harvest. There were significant effects (P value <0.0001).

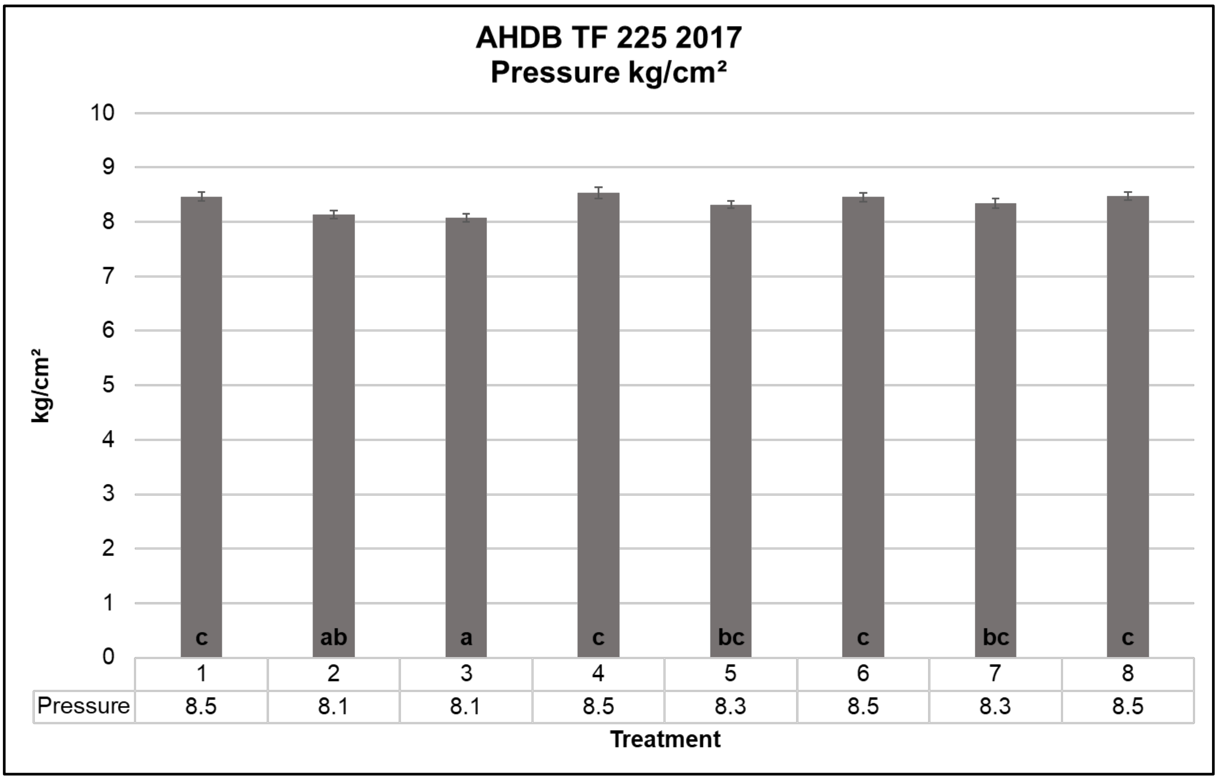


Figure 8.13. Fruit Firmness (kg cm^2). There were significant effects (P value <0.0001) of treatment on fruit firmness at harvest.

Fruit Dry Matter and Sugar Analysis

Fruitlet samples were harvested on 9 May, 13 July and 27 September 2017 and FDM analysis shows that application of Brevis had a transitory effect on raising FDM in fruitlets sampled in May (22% FDM) but failed to reach significance ($P<0.05$) compared to 19.5-20.6% FDM in other treatments (Figure 3.19).

As fruits developed and increased in fruit size FDM decreased to 16.7-17.1% FDM in samples sampled in July and 16.4-17.3% FDM in apples sampled at harvest.

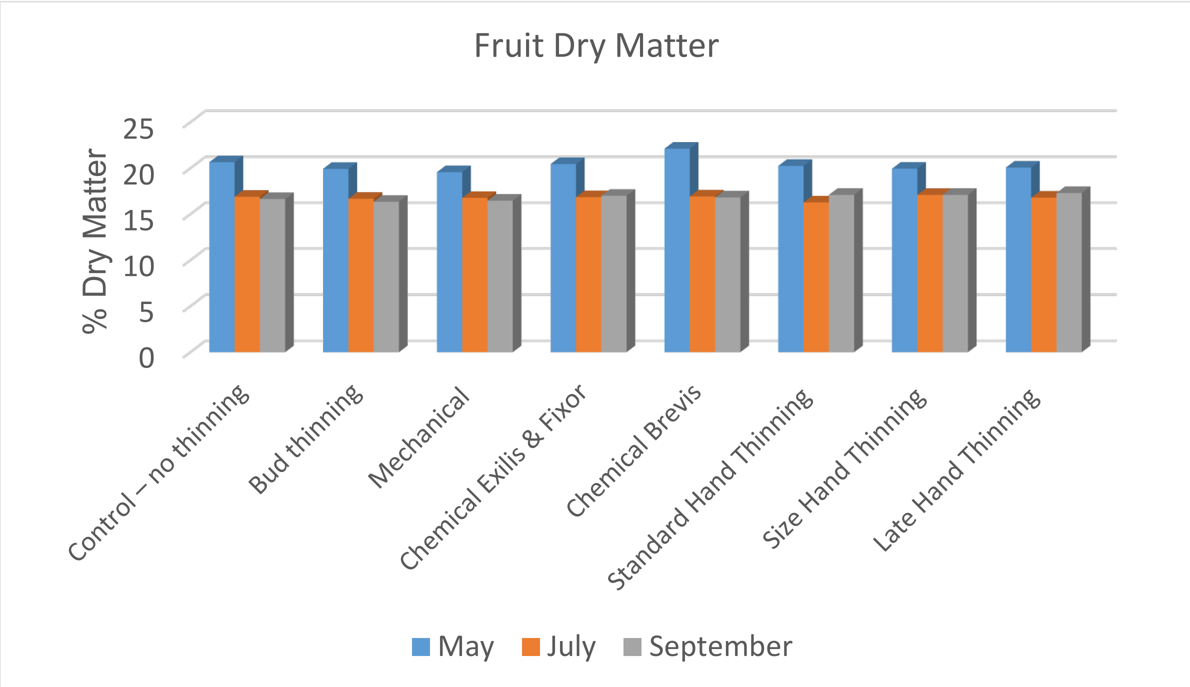


Figure 8.14. Fruit dry matter content (%) of Gala fruit picked. Each data point is the mean of 24 $LSD_{0.05}$ =1.67 on 70 d.f. Each sample consisted of 5-10 fruit (number of fruits per sample decreased through the season).

At harvest, the FDM was between 0.54% and 1.5 % higher than the fruit from the lower canopy (Figure 8.15). Fruit harvested from the upper canopy of tree subject to late thinning accumulated the highest amount of FDM (17.6%) (Figure 8.15).

Maturity of Gala at harvest showed a significant amount of starch clearance suggesting fruits were only suitable for short-term CA storage. The soluble solid content °Brix of fruit in general was low (~11.5%) except for fruit from Late Hand Thinning (Treatment 7) where °Brix at harvest averaged (13.3%).

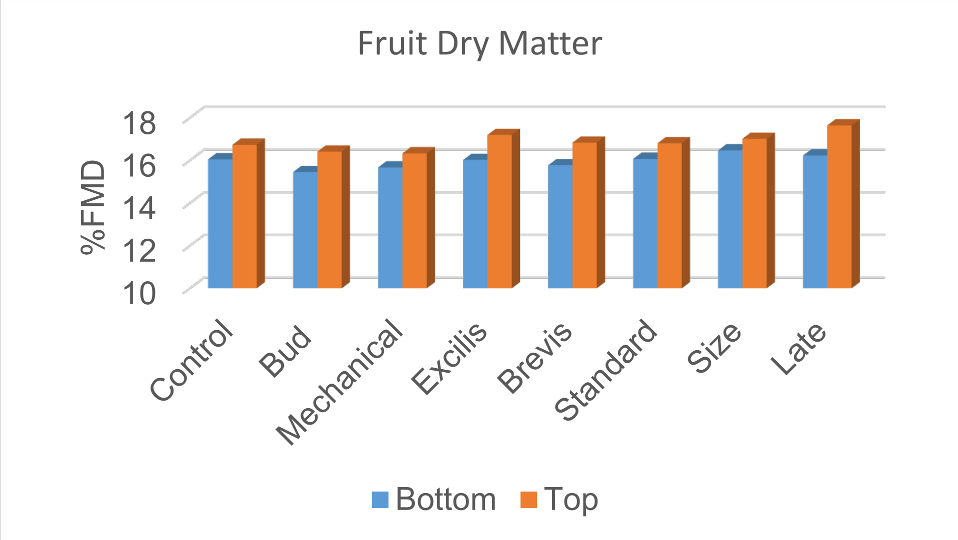


Figure 8.15. Positional effects of FDM accumulation between Gala sampled from the top of the canopy (>1.5 m) and bottom of the tree canopy (0.6 m) at harvest (27 September 2017). $LSD_{0.05}$ fruit position x thinning treatment = 1.08 on 44 d.f.

Sugar analysis of freeze-dried material of apple samples taken at harvest has shown that fructose content was higher (P<0.05) in fruit harvested from the lower canopy, while sucrose was highest (P<0.05) in fruit harvested from the upper canopy (Table 4.4). Treatment differences in fructose (Figure 8.15) and sucrose (Figure 8.16) content were not significant (P<0.05), however it was interesting to note that Brevis treated trees yielded fruit with the highest fructose content.

Table 4.4. Overall effect of tree position on the accumulation of Fructose and Sucrose (µl/µl) in Gala apples.

Tree position	Bottom	Top	P-value	$LSD_{0.05}$ 45 d.f.
Fructose	45.29	42.48	<0.01	1.06
Sucrose	24.84	27.18	0.02	1.435

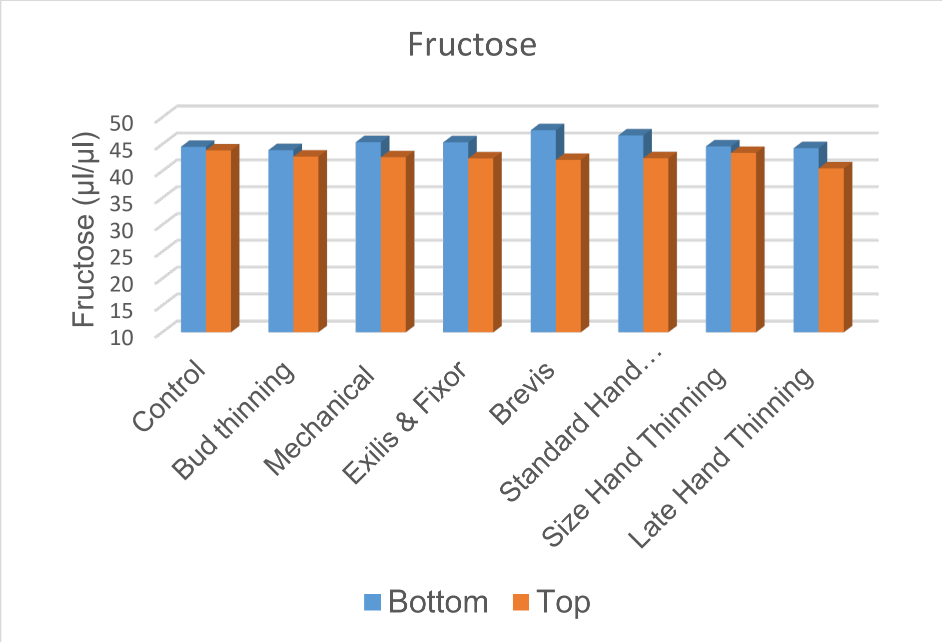


Figure 8.15. The effect of fruit position within the canopy and fruit and thinning practices on fructose content of Gala at harvest (27 September 2017); $LSD_{0.05}$ fruit position x treatment = 4.56 on 45 d.f.

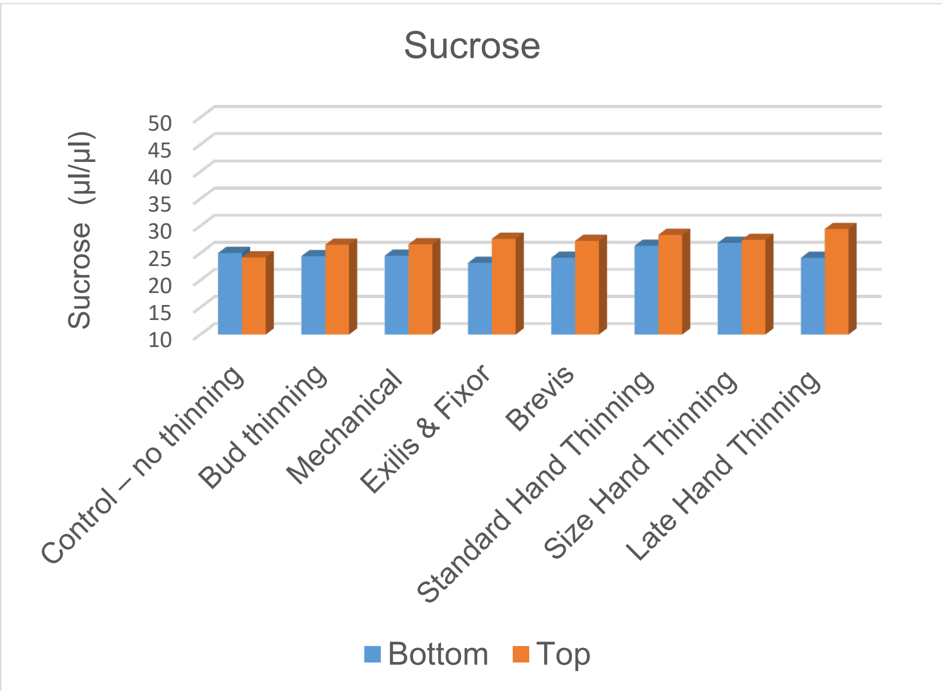


Figure 8.16. The effect of fruit position within the canopy and fruit and thinning practices on sucrose content of Gala at harvest (27 September 2017). $LSD_{0.05}$ fruit position x treatment = 4.059 on 45 d.f.

Late hand-thinning produced fruit with the highest (13.3%) sugar content (°Brix) at harvest (Figure 8.17).

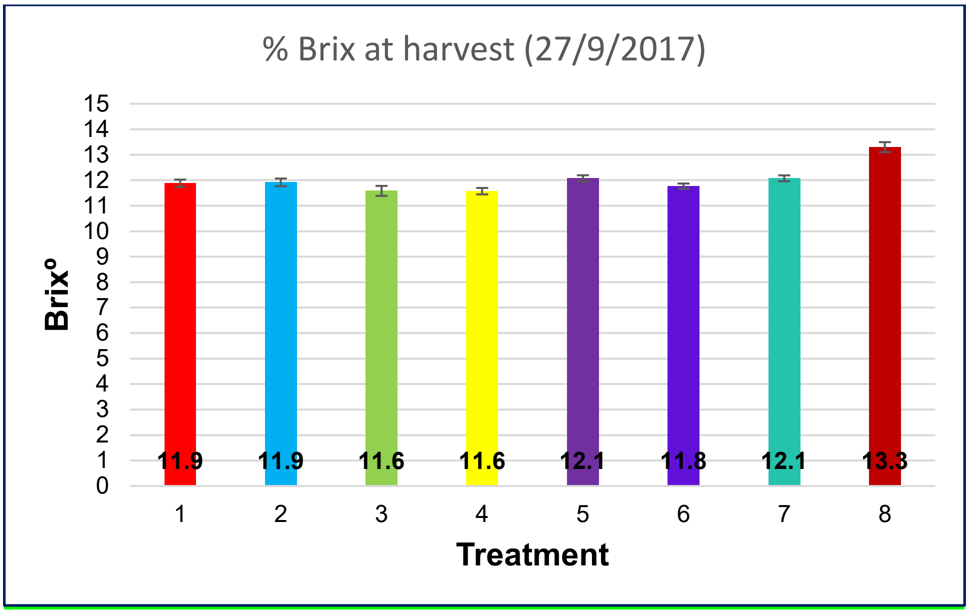


Figure 8.17. Soluble solids content (°Brix) of Gala apples subjects a range of bud and fruitlet thinning treatments.

Analysis of FDM content using a Felix-750 NIR dry matter analyser between top and bottom harvested fruit. Variability in FDM distribution was influenced by thinning technique, but no one technique increased FDM significantly. Fruit harvested from the lower canopy were more variable in FDM content than fruit from the top of the canopy (Figure 8.18).

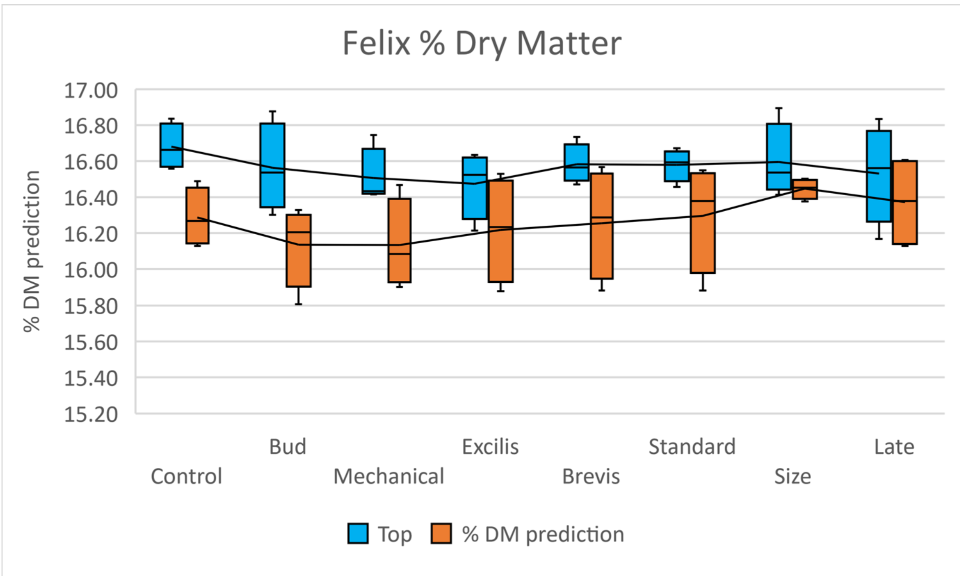


Figure 8.18. The Felix-750 NIR-Gala Model (NRI-UoG) predicting FDM content of apples at harvest subject to different thinning strategies (Fast LLP).

After removal from storage in 3% CO_2; 1% O_2, 0.5-1.0°C after five months, fruits were analysed for quality attributes. No significant difference was observed in fruit firmness (71.8-73.3N; 7.2-7.3 kg) across treatments, while sugar content was highest in late thinned fruit (13.9%) compared to mechanical thinned fruit where °Brix measured 12.2%. The incidence of rotting varied across the treatments with the highest recorded in hand thinned (Table 4.5).

Table 4.5. Fruit Quality Analysis after five months Storage (3% CO_2; 1% O_2), 0.5-1.0°C.

	Control	Bud Thinning	Mechanical	Exilis Fixor	Brevis	Std Hand Thinning	Size hand thinning	Late thinning	$LSD_{0.05}$
Firmness(N)	73.1	72.3	73.3	72.6	72.7	71.8	72.1	72.2	3.29
°Brix (%)	13.5	13.4	12.2	13.7	13.6	13.7	13.8	13.9	1.35
Rots (%)	1.3	1.6	1.3	2.5	1.3	2.8	6.25	0	5.30

Conversion of Firmness (N) to kg dived by 9.61.

The compositional changes with a reduction in the proportion of structural carbohydrate based on a FW basis during development is accounted for by cell expansion and the increase in cellular solutes in the form of sorbitol and sucrose (alcohol soluble sugars) entering the fruit initially through symplastic connections from the phloem while during the latter stages of fruit development apoplastic routes account for a significant proportion of solute movement into fruit cells.

Summary and Key Findings WP3

Significant damage occurs to fruit flowers at full bloom and early fruitlet during sub-zero temperatures (10% kill at -2.2ºC and 90% kill at -4ºC).

Frost damage caused significant losses causing excessive flower fall and lower than optimum yields (> 40 T/Ha) due to damaged fruit. Class 1 percentages were also affected and lower than commercial optimum (<85% Class 1)

The significant differences in the percentage of fruit fallen naturally and hand thinned between Treatments 6, 7 and 8 indicates that the early hand thinning may have been too early and fruit which may have fallen naturally later was picked off.

Despite the lack of significant effects of treatment upon yield and class in 2017, Treatments 3 and 4 Mechanical Thinning and Exilis may offer the grower the most cost-effective methods of thinning. Treatments 7 and 2 are also worth considering. All treatments had optimum fruit size between 120g and 130g.

There was very low disease pressure in 2017 and skin finish was good. Based on Waste Category analysis, the hand thinning methods may have removed any diseased fruit even though the operative aimed not to.

The Mechanical Thinning method may have delayed initial growth. The later leaf emergence and consequently later growth cessation may have shaded the fruit hence the poorer colour. Colour was generally poor in 2017.

Small fruit in the un-thinned control is expected.

Fructose was highest in fruits from the lower canopy, while sucrose was most abundant in fruit from the upper canopy.

FDM at harvest were similar across all treatments.

Trees subject to late thinning (fruit size 30mm to 40mm: BBCH 73-74), after second fruit fall produced fruit with the highest °Brix at harvest, but this effect was lost in storage.

April 2018-onwards (Season 3)

Information gained from the first year of study provided an informed basis for the applications of tree management strategies in Year 2 2017. These approaches to thinning will continue to be applied in subsequent years.

Strategies to manipulate crop load at different timings in a high FDM Gala orchard (FAST - Brogdale) will continue to be investigated and thinning strategies related to fruit quality.

Treatments 2018

1. **Control** no thinning
2. **Bud** thinning – BBCH 52-54 (end of bud swelling to mouse ear) via bud extinction using MAFCOT Equilifruit tool ratios, completed 24 March
3. **Mechanical** thinning – 60% first open flower (BBCH 65-66) (hand held device), completed 19 May
4. **Chemical Exilis** – Fine Exilis 6-Benzyladenine + Fixor (funded by Fine) (BBCH 70-72) (PGR), completed 23 May
5. **Chemical Brevis** – Adama Brevis 150 SG metamitron 15% (funded by Adama) (BBCH 70-71 & 71-72) (PGR), completed 23 May
6. **Hand Thinning Standard** – fruit size 15mm to 25mm (BBCH 71-72), pre/up to second fruit fall, completed 3 June
7. **Hand Thinning Size** – event 1 fruit size from 25mm to 30mm (BBCH 73), event 2 fruit size 40mm (BBCH 74), completed 14 June

8. **Hand Thinning Late** – fruit size 30mm to 40mm (BBCH 73-74), after second fruit fall- completed 3 July

Key findings 2018 FAST

- Fruit set good and crop load heavy – 100s of fruits from hand thinning.
- Disease pressure higher than in 2017.
- Little effect of chemical thinners noted.
- Dry summer affecting fruit size – predicted to be lower than optimum in unirrigated orchard.

Work Package 4: Chlorophyll fluorescence to optimise harvest date

Results from Year 2 confirmed data collected in the first year suggesting that changes in CF readings provided a 7-to-10-day earlier warning compared to starch clearance patterns alone in helping predict harvest date. Fruits were picked 7 to 10 days after the CF warning (CF-pick). When starch was 85-80% (starch warning), a second pick (Starch-pick) 3 to 4 days later was carried out simulating commercial practice of picking after starch warnings had passed (Figure 9.1 and Table 5.1).

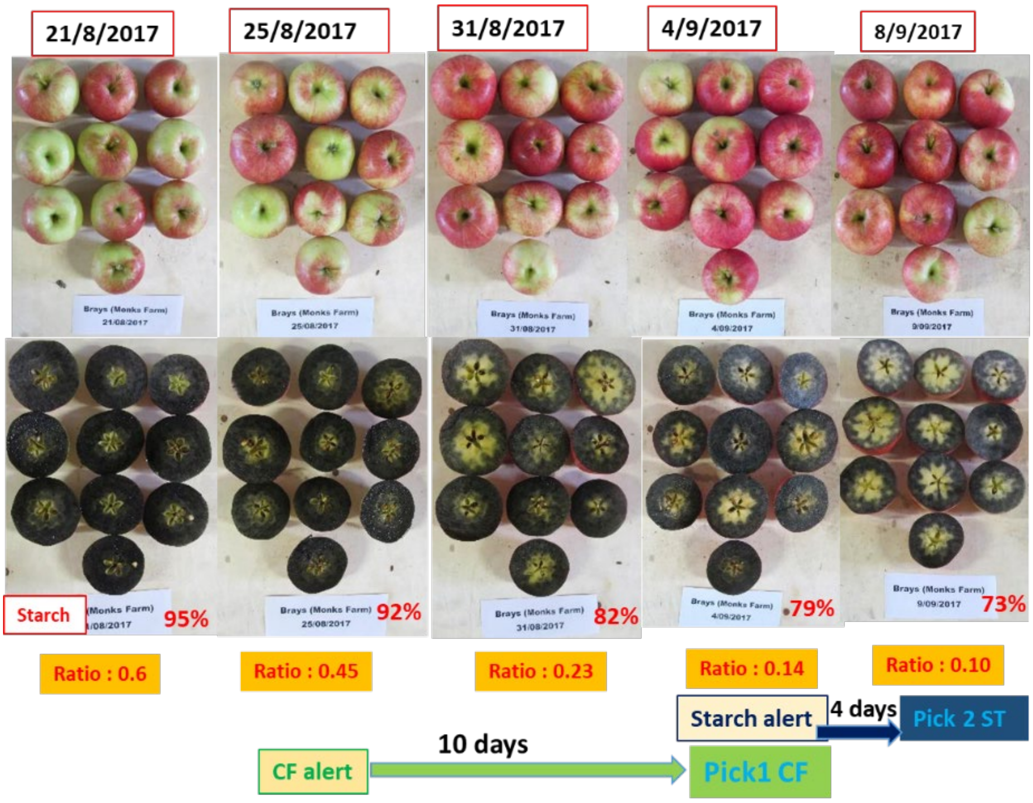


Figure 9.1. Comparison of early CF warning with starch index in one orchard (Monks), clone Mondial (2017).

Table 5.1. Comparison of fruit maturity warning by chlorophyll fluorescence Pocket PEA (CF) and starch (2017).

	AvF-STD (July)	AvF-STD (1 Aug)	AvF-STD (21 Aug)	AvF-STD (25 Aug)	AvF-STD (29 Aug)	AvF-STD (31 Aug)	AvF-STD (4 Sept)	AvF-STD (8 Sept)	AvF-STD (11 Sept)	AvF-STD (14 Sept)
Barnyard	4834	4268	2662	1666	1356	847	852	691	575	
Ratio to July		0.88	0.55	0.34	0.28	0.18	0.18	0.14	0.12	
				CF alert	7 days	CF pick	Starch pick			
Starch			90%	90%	82%	Starch alert	72%	60%	40%	
Monks	4358	3426	2661	1967	1832	1006	609	453	457	
Ratio to July		0.79	0.61	0.45	0.42	0.23	0.14	0.10	0.10	
				CF alert		10 days	CF pick	Starch pick		
Starch			95%	92%	90%	82%	Starch alert	73%	75%	
Gibbens	4751	4075	2814	2364	1916	1665	750	730	727	
Ratio to July		0.86	0.59	0.49	0.40	0.35	0.16	0.15	0.15	
				CF alert		10 days	CF pick	Starch pick		
Starch			90%	90%	89%	87%	Starch alert	72%	70%	
Hill Top	5270	3078	1892	1100	837	704	302	225	309	
Ratio to July		0.58	0.36	0.21	0.16	0.13	0.06	0.04	0.06	
			CF alert		10 days	CF pick	Starch pick			
Starch			89%	87%	82%	Starch alert	75%	60%	40%	
Mystole	3400	3336	2368	2245	1905	1443	1147	608	512	
Ratio to July		0.98	0.70	0.66	0.56	0.42	0.34	0.18	0.15	
						CF alert		10 days	CF pick	Starch pick
Starch			95%	94%	93%	91%	90%	87%	Starch alert	

A comparison of mineral analysis results between fruitlet until the end of storage in different orchards is shown in Table 5.2.

Table 5.2. Comparison of mineral analysis between fruitlet until end of storage in different orchards.

FIELDREF	Test	Clone	FMD	CF (AvF)	WT	Interpretation	N	Interpretation	P	Interpretation	K	Interpretation	Mg	Interpretation	Ca	Interpretation
Orchard A	Fruitlet (July 2017)	Schneiga	15.6	4664	36.34	Normal	87.36	Normal	13.62	Low	147.78	High	11.02	High	16.59	High
	Fruit (August 2017)		16	4703	97.71	Normal	35.2	Low	9.4	Very Low	94.28	Slightly Low	7.45	Normal	10.49	High
	Fruit (September 2017)		15.6	2747	138.34	Normal	34	Slightly low	11.14	Slightly low	117.38	Normal	6.12	High	10.02	High
	Fruit (May 2018) Cont		15.6	717	158.56	High	29.64	Low	11.49	Normal	110.29	Normal	5.76	High	10.06	High
	Fruit (May 2018) SF		15.4	790	162.2	High	32.34	Slightly low	10.32	Normal	115.55	Normal	6.56	High	10.06	High
Orchard B	Fruitlet (July 2017)	Mondial	13.2	5665	40.22	Normal	83.16	Normal	13.21	Low	135.24	Normal	10.04	Normal	14.42	Normal
	Fruit (August 2017)		14.6	4752	103.06	Normal	39.42	Slightly low	7.55	Very Low	87.9	Low	6.92	Normal	10.24	High
	Fruit (September 2017)		13.8	3685	134.89	Normal	26.22	Low	9.15	Low	109.93	Normal	5.34	High	8.89	Normal
	Fruit (May 2018) Cont		14.2	949	152.68	Normal	28.4	Low	9.27	Slightly low	111.6	Normal	5.56	High	8.41	High
	Fruit (May 2018) SF		14.8	1628	140.02	Normal	35.52	Slightly low	10.1	Normal	119.36	Normal	6.06	High	8.36	High
Orchard C	Fruitlet (July 2017)	Mondial	12.8	5983	46.57	Normal	67.84	Normal	13.1	Low	103.43	Slightly Low	8.08	Normal	15.43	High
	Fruit (August 2017)		13	5363	98.36	Normal	46.8	Normal	9.7	Low	85.76	Low	7.03	Normal	13.9	High
	Fruit (September 2017)		14	3641	134.44	Normal	37.8	Slightly low	11.12	Slightly low	96.59	Slightly low	5.48	High	10.2	High
	Fruit (May 2018) Cont		12.6	1004	173.8	High	31.5	Slightly low	9.65	Slightl low	96.93	Slightly low	4.91	Normal	9.08	High

	Fruit (May 2018) SF		14	1615	152.76	Normal	28	Low	9.89	Slightly low	96.32	Slightly low	5.25	High	8.88	High
Orchard D	Fruitlet (July 2017)	Galaxy	13.6	6441	49.59	Normal	72.08	Normal	11.16	Very Low	124.99	Normal	9.3	Normal	14.59	High
	Fruit (August 2017)		13.2	5163	88.01	Normal	36.96	Low	6.48	Very Low	71.29	Very Low	6.16	Normal	10.85	High
	Fruit (September 2017)		13.2	1993	143.52	Normal	33	Slightly low	7.34	Very Low	113.32	Normal	5.37	High	9.92	High
	Fruit (May 2018) Cont		14.6	501	177.18	High	27.74	Low	7.68	Very Low	86.19	Slightly low	5.23	High	9.21	High
	Fruit (May 2018) SF		13.2	1242	141.26	Normal	23.76	Low	6.86	Very Low	95.32	Slightly low	5.37	High	9.16	High
Orchard E	Fruitlet (July 2017)	Mondial	13.4	6602	58.42	Normal	73.7	High	15.01	Normal	144.37	High	8.82	Normal	14.53	High
	Fruit (August 2017)		14	5403	135.49	High	36.4	Slightly low	8.7	Low	84.04	Low	6.04	Normal	8.99	High
	Fruit (September 2017)		12.4	2850	175.1	High	37.2	Slightly low	8.86	Low	98.26	Slightly Low	5.17	High	7.36	Normal
	Fruit (May 2018) Cont		13	1636	188.22	High	32.5	Slightly low	8.46	Low	96.47	Slightly Low	5.21	High	8.29	High
	Fruit (May 2018) SF		13.2	1038	155.38	High	29.04	Low	8.63	Low	88.76	Slightly Low	4.99	Normal	9.48	High

Generally, chlorophyll fluorescence decreased during storage in comparison with harvest; however, most SmartFresh treated samples maintained more active chloroplasts especially when fruits were harvested earlier as part of the CF pick (Figure 9.2).

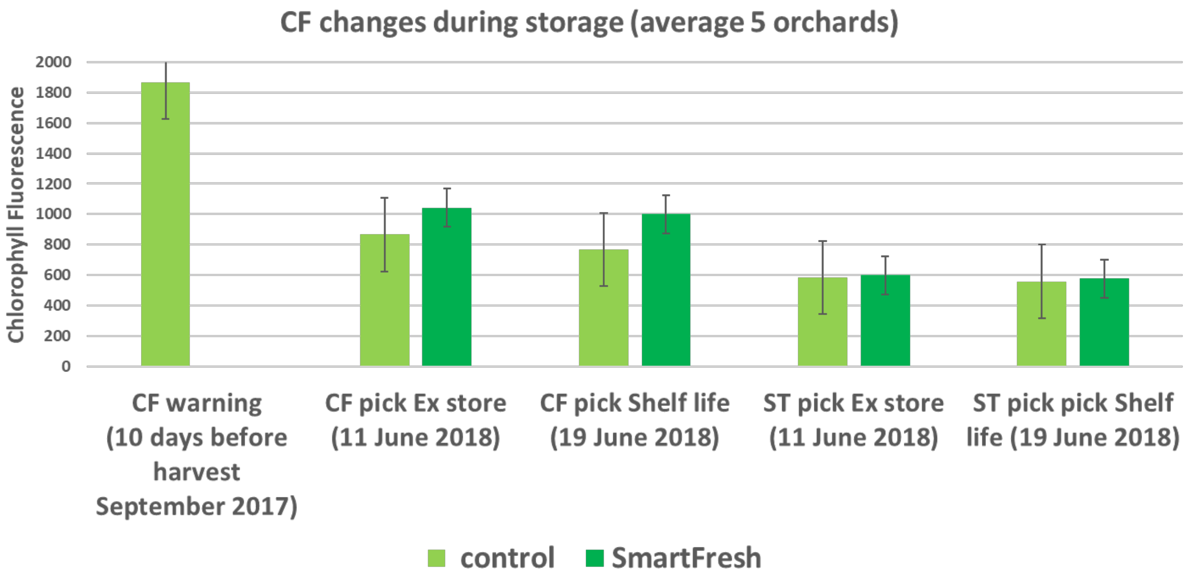


Figure 9.2. Comparison of chlorophyll fluorescence changes between CF warning at harvest (September 2017), after nine months storage and seven days shelf life - samples collected as CF pick and starch pick and treated or untreated with SmartFresh.

In some instances, SmartFresh slowed the rate of CF degradation, and helped to maintain quality during shelf life as well as maintaining chlorophyll fluorescence as an indicator of improved quality of the fruit for keeping longer in store.

Chlorophyll fluorescence levels in one orchard were lower than others tested and presented poorer storage quality attributes in long term storage. While fruit from this orchard was of high FDM, these results indicate that optimising fruit from long term storage requires good control of harvest maturity. While fruits with high FDM may prove the best eating quality during long-term storage, other harvest maturity-based parameters should not be overlooked.

A correlation exists between dry matter before harvest and the maximum value of °Brix during storage (Figure 9.3) and confirms the earlier work of Palmer *et al* (2010). However, the timing of optimum soluble solids accumulation was less easy to predict based on FDM data alone. In samples from one orchard with higher FDM (15.6%) maximum °Brix occurred in April and in samples from another orchard with lower FDM (13.2%), the maximum °Brix occurred in June. In some samples, although °Brix at harvest was lower than industry standards (ºBrix >12%) it increased significantly during storage (Figure 9.3).

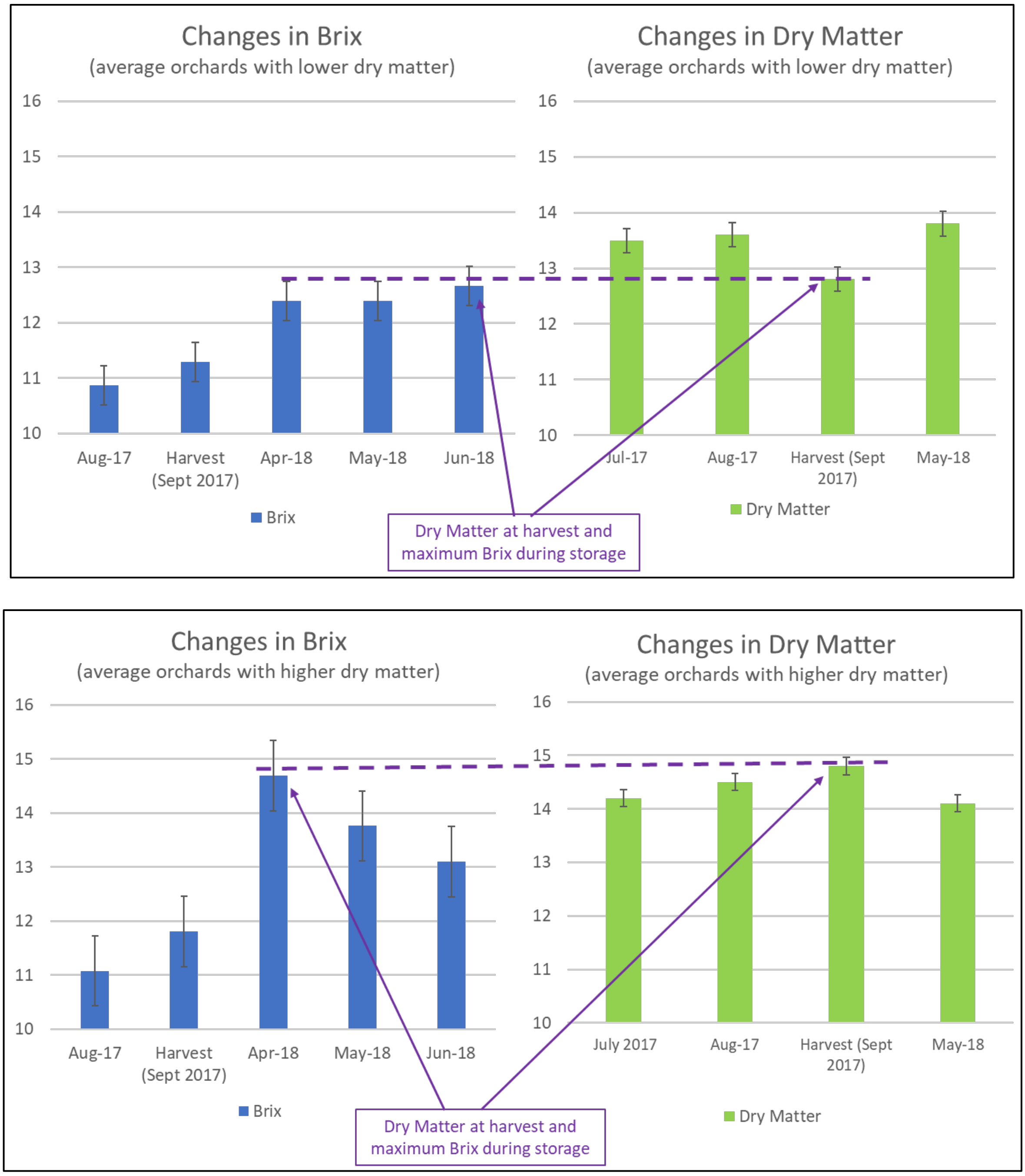


Figure 9.3. Dry matter at harvest was an indicator of the maximum °Brix that occurred later during storage.

Fruit acidity and sugars as measured by °Brix concentrations change during storage; however, if fruit is picked at the optimal maturity, then the decline in acidity and sugars can be more rigorously controlled and CF can help to maintain fruit quality in store by optimising picking dates based on fruit maturity.

In general, SmartFresh-treated samples have retained a higher acidity in stored samples but just failed to reach significance (P<0.05). Maintenance of sufficient acidity has an important effect on flavour perception; in general, acidity decreases with later harvesting, and this can affect fruit taste in long term storage (Figure 9.4).

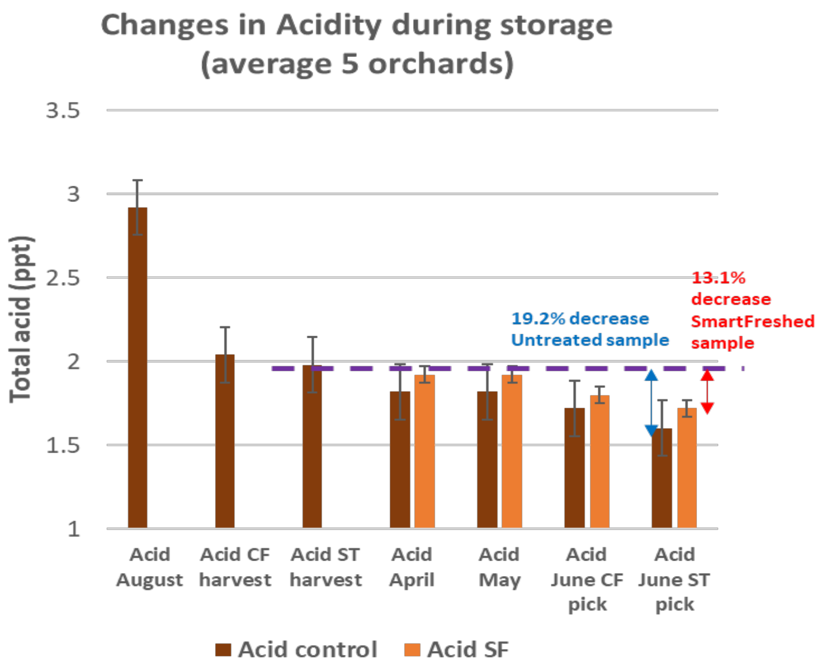


Figure 9.4. Comparison of percentage changes in acidity between samples treated with SmartFresh and untreated samples.

In Gala stored after April in 5% CO_2, 1% O_2 (0.5-1.0°C) SmartFresh treated samples retained firmness for longer especially during shelf life in samples assessed in May and June (Figure 9.5).

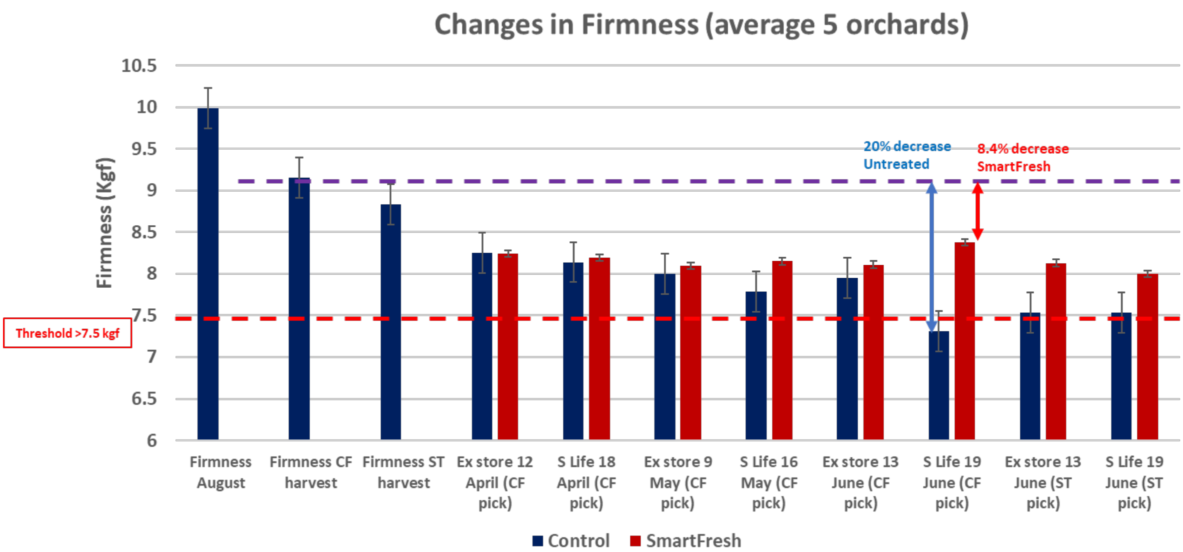


Figure 9.5. Comparison of changes in firmness of SmartFresh treated and untreated fruit during storage.

Discussion Work Packages 1-4

Dry matter accumulation of fruit is dependent on the position of fruits within the canopy. Fruits from the high (>1.5 m) canopy from the thinning trial were approximately 0.5% to 1.0% higher in FDM (16.4% - 17.6%) than fruits picked from the lower regions of the canopy (<0.6 m) where fruit averaged 15.45% to 16.47% FDM. This split was similar to data collected in Year 1 where fruits were sampled from a commercial orchard.

High sunlight interception throughout fruit development and possibly as early as bud development in the previous season will impact subsequent fruit quality. Increasing the amount of light interception by centrifugal pruning techniques affords the opportunity to improve tree performance above existing standard spindle tree architecture systems supported on post and wire structures. Laying down reflective mulches at key developmental stages in the life cycle of fruit buds and developing fruits demonstrates the importance of improving light interception within the orchard on fruit quality at harvest.

Previous reports (Palmer 2010; McGlone 2003) highlight a strong relationship between overall FDM and the amount of sugar (°Brix) in the crop at harvest and that this relationship carries on during the early stages of storage (3 months).

Analysis of fruits from the second year's trial suggest Gala from the upper canopy with high FDM retained elevated sugar content throughout 5 months of CA (3% CO_2, 1%O_2, 0.5-1.0ºC) storage. While fruit from the upper canopy intercepts more sunlight, increasing light penetration with centrifugal pruning failed to increase FDM; moreover, the positioning of reflective covers within the alleyways did not increase FDM. However, the 2016/17 season was the first year of conversion where significant pruning had been undertaken and the difference between training systems is likely to be greater than in subsequent years.

In this first year of implementing bud and flower thinning strategies no significant impact on FMD content was observed. Early frosts during flowering at the FAST LLP site impacted on crop load and may have influenced the source sink relationships of the different treatments.

Other factors such as soil, tree age and rootstock will clearly affect tree architecture, resource allocation and precocity of flowering and fruit set. Therefore, a complex interaction between many agronomic factors plays a part in influencing portioning of carbohydrate into fruits. Some of these factors are more amenable to manipulation than others.

Brevis removed over twice the number of fruitlets compared to natural drop in the control trees but did not reduce the overall yield of trees compared to the control; while yield per tree was similar to the control, the yield of Class 1 fruit was slightly lower than the control. That the removal of twice the number of fruits per tree failed to increase FDM portioning into fruit suggests there is a certain degree of plasticity within the tree. While thinning strategies to remove fruit numbers based on branch thickness using the Mafcot Equilifruit tool goes some way in manipulating crop load related to tree architecture a greater understanding of maximising crop load for tree canopy using Lidar may be a way forward.

Interestingly, sugar analysis of tissue samples taken at harvest while not showing significant difference between treatments found that fruit taken from the lower canopy were higher in fructose and lower in sucrose than fruit taken higher up the canopy. Considering apples were lower in FDM in the lower canopy it might suggest fruits are maturing earlier in the lower canopy as more of the starch is hydrolysed into sucrose and then into fructose and glucose.

Analysis of existing FMD data sets of 56 orchards provided by FAST LLP using Pearsons Correlations and multiple regression analysis of over 3 years' data of FDM against leaf and fruit mineral analysis found weak positive correlation with Fe, K, Mg, P K:Ca ratio. Leaves under Mg and K deficiency hold on to their photosynthates and are less likely to partition carbohydrates to roots (Cakmak et al 1994) or other sink organs such as fruits. Zhoa (2001) reported that K deficiencies in cotton plants led to lower chlorophyll content, poor chloroplast ultrastructure and reduced translocation of sugars due to reduced entry of sucrose in the transport pool or lower phloem loading. Increasing leaf Mg and K may help to encourage greater translocation of photosynthates into fruits increasing FDM. Importantly, Mg and K act as antagonists to calcium binding to pectin in the middle lamella and pectins within the cell wall; increasing fruit Mg and K excessively could have implications for the long-term storage capacity of fruit unless fruit calcium concentrations can be increased at the same time.

Being able to predict the onset of changes in starch clearance patterns before such changes in maturity happen offers some interesting options for the future management of harvest maturity prediction. Chloroplast fluorescence is an indirect measure of plant health; when tissues age, the amount of energy released in the form of fluorescence increases because energy escapes through the photosynthetic II (PSII) pathway, as the efficiency of the pathway is lost.

While an increase in ethylene synthesis charts the start of the respiratory climacteric, the magnitude and duration of the rise is variety specific. Additional studies on the relationship between internal ethylene and starch clearance patterns has found a tight correlation exists when IEC's <100 ppb and starch content are high (80-95 %); once starch clearance patterns drop below 75% significant variability in the corresponding IEC's exist. With this is mind CF might provide an additional insight into changes in starch clearance. However, it is important to consider that as the relationship between ethylene and starch clearance is not tightly linked as maturity proceeds, any measure attempting to correlate maturity may encounter inherent problems.

Conclusions Work Packages 1-4

WP1: Meta-analysis of fruit dry matter

Meta analysis of existing data sets showed a weak positive correlation with higher K and Mg content in fruit with higher FDM while excess zinc was considered detrimental to FDM accumulation.

WP2: Centrifugal pruning and reflective mulches

Centrifugal Pruning increased light penetration and interception (41.5%) throughout the canopy compared to Tall Spindle trees (34.4%). Positioning of reflective covers increased yield by 5% in CS trees and 19% in TS trees.

WP3: Bud, flower and fruitlet thinning strategies

None of the techniques increased FDM significantly and FDM at harvest were similar across all treatments. 2017 was a difficult year to predict how much to thin and the yield and grade out were affected by frost but size, quality and maturity parameters were acceptable for all treatments. Late thinning increased °Brix and hand thinning may encourage larger fruit to develop. Treatments 3 and 4 (mechanical and chemical Exilis) had the best results in 2017; Treatment 7 (Size) appears to be the best of the hand thinning treatments. Overall higher fructose content was found in fruit from the lower canopy while higher sucrose content was found in fruit in the upper canopy which may be a reflection on rate of fruit maturation. Effects of increased °Brix at harvest for later thinning treatments were lost in storage.

WP4: Chlorophyll fluorescence to predict optimal harvest date for Gala apples

Confirmation of the first two seasons of the prediction model gave 7 to 10 days' early warning for picking samples which could be a valuable logistical and planning tool to help in the harvest strategy decision making process. Also, storage monitoring results showed the possibility of storage of English Gala with a good quality for more than 9 months if fruit has been picked at the right time with good balance of minerals and high dry matter and being stored in the right conditions with application of SmartFresh to maintain quality of fruit.

Objectives

1. To carry out a meta-analysis to provide an evidenced-based understanding how fruit FDM can be manipulated to optimise fruit quality. Achieved.
2. To determine the impact of increasing light interception by pruning and/or using reflective mulches at different stages of fruit development on fruit quality, FDM, storability and consumer acceptability. Partially achieved and ongoing.

3. To quantify the impact of thinning treatments on fruit quality, FDM, storability and consumer acceptability and to develop recommendations for thinning strategies to optimise yield of high quality fruit. Partially achieved and ongoing.
4. To identify the correct timing for harvesting orchards with a high FDM to maximise the eating quality of fruit in the April to June marketing window, and to establish and validate a protocol using chlorophyll fluorescence to predict this timing. Partially achieved and ongoing.
5. To maximise knowledge exchange and communications interaction with international research groups to enhance this research programme. Partially achieved.
6. To carry out effective project management and mitigation of risks. Partially achieved.

Knowledge and Technology Transfer

Lecourt, J and Colgan, R.J Agronomist day Demonstration of pruning and reflective mulches. September 2018. (NIAB-EMR)

Dalton, A.F. Thinning Effects on Fruit Dry Matter. Fruit Science Live Event (FAST, ICL & BASF). 24 July 2018.

Colgan, R.J. Optimising Fruit Dry Matter for long-term storage of Gala. AHDB Tree Fruit Panel meeting 6 March 2018.

Dalton, A.F. Thinning Effects on Fruit Dry Matter. AHDB Tree Fruit Panel meeting 6 March 2018.

Dalton, A.F. Thinning Effects on Fruit Dry Matter. AHDB Tree Fruit Day 22 February 2018.

Lecourt, J. Centrifugal Pruning. AHDB Tree Fruit Day 22 February 2018.

Merhdad, M. Application of chlorophyll fluorescence to predict fruit maturity in Gala Apples. AHDB Tree Fruit Day 22 February 2018.

Dalton, A.F. Thinning Effects on Fruit Dry Matter. FAST LLP Members Conference 1 February 2018.

Lecourt, J and Colgan, R.J Agronomist day Demonstration of pruning and reflective mulches. 13 September 2017. (NIAB-EMR)

Colgan, R.J. & Lecourt, J. Optimising Fruit Dry Matter for long-term storage of Gala. AHDB-Tree Fruit day, 23 February 2017. (NIAB-EMR)

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APPENDIX 1 WP 3 CHEMICAL APPLICATION GUIDELINES

Chemical thinners were applied using manufacturers' recommendations (see product label and SDS) AND adapted according to weather conditions before, during and after application:

Exilis + Fixor (100 g/l NAA)

- 8-10mm fruit size (no treatments on fruits larger than 10mm)
- Temperatures should be increasing to an expected daily maximum of 15ºC to 28ºC at application and continuing for 3 to 5 days afterwards
- If conditions not suitable at 8-10mm, Fixor may be omitted from application (but check with Fine first)
- Products should not be applied in temperatures under 15ºC, over 28ºC, frosty or slow drying conditions.
- Fruit size can increase in 1 week from 11 to 15 mm if hot.

Brevis

- 8-10mm fruit size application 1
- 12-14mm fruit size application 2
- 5 days minimum in between and
- 2 to 3 days optimal conditions before and after application comprising:
    - medium solar radiation and
    - <10ºC night time temperatures.
- At moment of application temperatures are not important
- Product should not be applied when night time temperatures are over 10ºC nor when night frosts are predicted.
- Thinning will be stronger when the night temperatures are between 10 - 15ºC in the week before application and radiation is below 1600J/cm^2.
- Thinning will be weaker when in the week before application the night temperatures are between 5-10ºC and radiation is above 1600J/cm^2.
- The fruitlet stage is less important than the climatic conditions before and after the application, but before 6 mm and after 16 mm efficacy is less.
- Any second application may be done to top of tree only.
- When trees are vigorous, thinning effect will be stronger (more competition on carbohydrates)
- Older trees are more difficult to thin than young trees
- Gala, Fuij, Junami and Elstar are more difficult to thin than Golden and Braeburn

- BREVIS should not be applied with foliar feeds as this can enhance the thinning effect
- Gibberelins, oily products or foliar feeds should not be applied directly before BREVIS (at least 1 week of interval)

APPENDIX 2 WP 3 CHRONOLOGY 2017

DATE	ACTION
13-Mar	Trial plot labelled avoiding non standard trees.
16-Mar	Bud stage monitoring commenced for bud burst and bud extinction thinning.
17-Mar	Pruning commenced.
20-Mar	Bud stages assessed.
24-Mar	BBCH 54 mouse ear. **Treatment 2 Bud Extinction thinning 1 of 1.** 6 buds per cm2 used as per MAFCOT Equilifruit gauge.
27-Mar	Pruning completed.
12-Apr	BBCH 60 first flowers open.
13-Apr	Bud stages assessed.
18-Apr	BBCH 65 full bloom. Temperatures of -1.2°C over night (10% damage occurs at -2.2°C full bloom).
19-Apr	Temperatures of -1.6°C over night. **Treatment 3 Mechanical thinning 1 of 1** with Infacor Powercoup Electroflor Blossom Thinner at 65-66 60% open flower (when first petals falling). 1/3 thinning of petals/fruitlets removed including underneath fruit where possible and 1/2 thinning on tops (to reduce damage to remaining tissue & subsequent ethylene release).
20-Apr	Temperatures of -3.4 over night (90% can occur at -4°C).
25-Apr	1 week post full bloom. Temperatures of -0.8°C over night.
26-Apr	LMA samples collected from guard trees.
27-Apr	Temperatures of -1.1°C over night. Minimal frost damage to petals noticed. Collection vessels for natural fruit drop situated. Assess fruitlets after 24 hours (if green recepticles = ok).
28-Apr	Primary mildew affected shoots removed - removing new growth away from fruitlets will not have much effect on DM so no need to count how many from each treatment tree.
03-May	BBCH 67 flowers fading majority of petals fallen.
09-May	**Dry matter sampling event 1 of 3.**
10-May	Temperatures of 0°C to -2.5°C minimum for 7 hours.
11-May	Fruit size assessment for T4 and T5.
12-May	SDHI applied by farm this week.
15-May	*Fruit size = 80mm.*
16-May	**Dry matter sampling event 2 of 3.**
17-May	*Fruit size = 90mm.*
19-May	*Fruit size = 100mm*
22-May	*Fruit size = 120mm.* Flowers collected from first drop.
23-May	**T4 & T5 applications.** Exilis a in 500L & Fixor 0.1 in 500L. Brevis 1.65 in 1000L. Temperatures previously <10 & day time temps predicted to be over 15.
24-May	Temperature overnight 12°C to 14°C.
25-May	Fruit size 140mm. NO SPRAY TODAY of Sercadis because of gibberelins & reaction with chemical thinners
28-May	T5 5 days post application.
31-May	*Fruit size 210mm for T6.*
02-Jun	Second fruit fall started. Fruit collected from T6. Client visit. Treatment 4 10 days post application. No effect from products yet.
03-Jun	**T6 hand thinning** (fruit size between 15mm and 25mm).
05-Jun	*Fruit size = 250mm for T7.*
06-Jun	Fallen fruit collected from T7 & T8.
09-Jun	*Fruit size = 290mm* . T4 & T5 = some fruit dropped, more from T5 but v variable. Second fruit fall continues.
12-Jun	*Fruit size for 300mm.* 21 days post application T4 & T5 = no counts yet as June drop still occurring
15-Jun	**T7 hand thinning event 1 of 2.** Based on size prediction at harvest of 20.5mm = 60mm, 25.6 = 65mm and 30.6 = 70mm, all below 26mm removed.
16-Jun	*Fruit size 340mm for T8.*
21-Jun	*Fruit size 360mm.*
29-Jun	Collect & count fruit from second fruit fall all remaining treatment. Counts commenced.
30-Jun	**T8 hand thinning event 1 of 1** at 40mm (actual 40.3mm).
03-Jul	**T7 thinning event 2 of 2** = anything below 34.3mm removed (based on predicted size at harvest).
12-Jul	Husbandry pruning tops commenced.
21-Jul	Client visit.
31-Jul	1 fallen tree row 3 T4 middle tree picked all fruit - weighed = 11.325kg & graded.
01-Aug	Crop monitoring throughout August.
04-Sep	Starch test starch = 89.7. Aiming for 80% at harvest
11-Sep	Starch test = 88.6%, pressures 8.8kg.
12-Sep	Fruit sampled for FMA.
14-Sep	Fruit sampling for maturity - 10 fruit from guard trees all 4 rows. Average starch 86%, pressure 8.6kg, BRIX 12%, Streif 2.1. Recommended pick date 18 September.
18-Sep	Photos taken of all 3 tree treatment plots.
19-Sep	Fruit sampling for quality 32 x 60s . **Dry matter sampling 3 of 3.**
20-Sep	**HARVEST** - picked by 3 tree plot. Fruit maturity assessments - pressure, BRIX & starch = 10 fruit per treatment plot.
11-Oct	Quality assessment commenced. Guards and spare trees harvest commenced.
12-Oct	Quality assessment continued.
13-Oct	Quality assessment completed.
16-Oct	Guards and spares harvests complete.

APPENDIX 3 WP 3 PHOTOGRAPHS

Treatment 3 bud thinning before

Treatment 3 bud thinning after

Treatment 4 mechanical thinning before

Treatment 4 mechanical thinning after

Apple catchers

Fruit fall counting

Treatment 8 after late hand thinning

Treatment 1 at harvest