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Key staff:	Emma Worrall Jessica Sparkes Harriet Roberts
Location of project:	ADAS Boxworth
Industry Representative:	Nigel Kitney, Herefordshire
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DISCLAIMER

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

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.

Chris Nicholson

Horticultural consultant

ADAS UK Ltd.

Signature .... Date 28 November 2014

Harriet Roberts

Horticultural consultant

ADAS UK Ltd.

Signature Date 28 November 2014

Report authorised by:

Barry Mulholland

Head of Horticulture

ADAS UK Ltd.

Signature Date 28 November 2014

CONTENTS

Grower Summary 7

Headline 7

Aims and objectives 7

Summary of the project 8

Recommendations 10

Financial comparisons 11

Science Section 12

Fruit set and fruit drop 13

Fruit quality in apples 16

Firmness 16

Dry matter content 16

Carbohydrate and acid content 16

Colour 17

Fruit shape 17

Storage 17

The effect of crop load on fruit quality 18

Optimum crop load 19

Methods to achieve optimum crop load 20

Reduction of number of floral buds by winter pruning 20

Inhibition of flower bud formation 21

Preventing fruit set by flower thinning 22

Reducing crop load by fruitlet thinning 22

Control of pre-harvest drop 22

Hand thinning....23
Chemical thinning....24
- Ammonium thiosulphate (ATS)....24
- 6-Benzyladenine (BA)....25
- Ethephon....26
- 1-naphthalene acetic acid (NAA)....27

Mechanical thinning....27
Effect of thinning timing....28
Effect on fruit quality....29
- Chemical thinners....29
- Mechanical thinners....31

Effect on storability....31
Effect on tree health....32
Chemical thinners....33
- Metamitron....33
- Other novel chemicals....35
- Tank mixes and adjuvants....36

Mechanical thinning....36
- Darwin string thinner....37
- BAUM thinner....39
- Drum shaker thinner....41
- Hand held mechanical thinners....42

Novel mechanical approaches....43
The use of models....44
- Precision crop load management....45
- Benefits of models to UK growers....46

Shading....47

Imaging technologies..48
Conclusions 50
Recommendations - Opportunities for future studies..51
Cost comparison of novel and combined of approaches 53
Appendix 1: Persons contacted through the course of the review 65

GROWER SUMMARY

Headline

This project has reviewed the latest scientific research, historical information and grower experience from around the world on fruit thinning and recommendations have been made for further study or investigation.

Background and expected deliverables

The overall aim of this project was to conduct a review of tree fruit thinning, primarily focusing on apple crops, but information from other tree fruit types was included where relevant, from both the UK and overseas. The review has identified potential areas of development of thinning practices in the UK which are economically viable and achieve optimum tree and fruit quality.

The specific project objectives were to:

1. Identify the gaps in our understanding of the physiology of fruit setting and fruit drop, and the control and management of these in relation to the different fruit thinning techniques to optimise fruit quality, size, cropping potential and also other aspects of fruit quality, particularly in relation to fruit storage;
2. Review and collate relevant UK and overseas information using, scientific literature, interviews with relevant stakeholders and researchers and other relevant UK and international sources regarding new technologies and or approaches to the science and practice of optimising fruit thinning;
3. Identify opportunities for future studies to examine appropriate and novel methods for flower and fruit thinning (including combinations of approaches) to optimise fruit quality and storability, either practiced or in development;
4. Provide a simple cost comparison of novel approaches or combinations of approaches if accurate information could be sourced.

Summary of the project findings

The biochemical processes involved in fruit set and fruit drop are complex and are controlled by a wide variety of parameters including; plant hormones, pollination, availability of water and nutrients, orchard practices (such as pruning, cultivation, nutrition and plant protection product use), light, temperature, humidity and soil conditions. Understanding these, and how thinning approaches are acting upon them, is critical for optimum reduction in fruit number. The decision over which thinning strategy to use to provide the best results is complex and will vary from orchard to orchard and season to season; furthermore, a combination of strategies will evolve each season. This review has demonstrated that the UK approaches to fruit thinning, in comparison with world practices, are very similar. Although we may have fewer chemicals at our disposal than some nations, very similar challenges are experienced by growers all around the world.

It appears that UK growers are perhaps more wary about using mechanical thinners than overseas growers. This is borne out by the fact that just 16 Darwin machines have been sold in the UK. Trials both in the UK and overseas show very promising results and as we improve their use and investigate more about their long term effects, such machines are likely to prove to be cost effective options for our cooler climate.

In terms of chemicals, gaining approval for metamitron in the UK is an exciting prospect as it appears to be a less temperature dependent fruitlet thinner than alternatives whose efficacy can be adversely affected by low temperatures following application. Some research has investigated the use of salts and oils as thinning agents. These present opportunities for organic systems but they too can be influenced by temperature, humidity, crop growth stage and spray coverage, leading to unpredictable results. Commercial growers currently focus on gaining optimum results using products already available, either in combination or with adjuvants. They also use tools such as the MaluSim and Fruitlet Growth models to inform the timing of chemical fruit thinning applications and their rates of use.

A key objective of this review was to consider how different thinning techniques affect different apple qualities and in particular, storage potential. Following a wide literature search it became clear that little work has focused on this topic. The literature which cites fruit quality parameters such as firmness and Brix, offers some very mixed conclusions. When compared to hand thinning and no thinning, both mechanical and chemical thinning strategies demonstrated both positive and negative effects. With a desire in the UK to store apples (particularly Gala) for longer, it would be very valuable to understand these effects.

Recent work carried out for the HDC (Project TF 222), has highlighted the importance of dry matter content (DMC) for fruit quality. It is clear that further work needs to be carried out to demonstrate how practices such as thinning could affect fruit quality characteristics such as DMC. The majority of the evidence from literature suggests that the size of the crop load, rather than the way that crop load was achieved, will have a greater effect on crop quality and storability. However claims have been made in more than one paper of improved fruit firmness and sugar content in both mechanically and chemically thinned fruit, suggesting that the method of thinning could influence storage potential.

Little or no research appears to have been done to assess the effect of different thinning techniques on the long term health of trees. Anecdotal evidence from growers using mechanical thinners around Lake Constance in Germany has so far not shown any long term detriment. However further work will need to be done in this area comparing methods to ensure that growers are not compromising future crops by thinning in certain ways.

Overall, this review has highlighted how complex apple thinning is and how many different factors are involved in determining the effectiveness of selected thinning strategies. In the UK, a variety of tools and options are available to growers; integrating their use to achieve optimum marketable fruit yield is the next step. This review has further demonstrated the potential of mechanical thinning and identified some new chemistry which may offer future potential in the UK. It has also highlighted some models developed in the USA to help growers reduce the uncertainty of chemical thinning, both in terms of when to thin, chemical concentrations to use and how effective thinning may have been according to the environmental conditions. Development of these types of models for UK systems and conditions would help to target the timing and likely impact of using selected thinning techniques on productivity. Their use alongside imaging technologies to inform optimum winter pruning strategies, alongside integration with mechanical techniques, would take some of the uncertainty out of the process of thinning and hopefully improve efficacy and cost effectiveness.

More comprehensive information gathered from this review is set out in the main Science section of this report. This includes information on fruit quality, the effect of crop load, methods to achieve the correct crop load, hand thinning, mechanical thinning, the timing of thinning and the effect of thinning on fruit quality, storability and tree health. Details are also included on chemical thinners, mechanical thinners, models, shading, imaging technologies and cost comparisons of different thinning systems.

Recommendations

Through the course of this review it became clear that tree fruit thinning is a complex and highly variable process; there is no single approach that can be applied to all crop types to achieve optimum tree fruit thinning. Current methods have their limitations and there are gaps in our knowledge and understanding of how current thinning methods work and what type of effect these methods could be having on fruit quality and tree health. We therefore recommend the following research themes for future studies to try to address the uncertainties associated with thinning and support the UK industry to thin more effectively and consistently:

1. A targeted comparison of commercial growing practices, including thinning, to identify those having greatest impact on the fruit storage potential of Gala and Braeburn;
2. Fully replicated trials comparing thinning methods and the effects on fruit storage ability. These should be compared with hand or no thinning controls. Methods to include mechanical, chemical and combined approaches;
3. Physiological study of Gala looking at components of yield and fruit storage ability;
4. Develop Precision Crop Load Management tools for the UK, using the MaluSim and Fruitlet Growth models to inform chemical fruit thinning and achieve optimum results;
5. To keep up to date with the newest chemistry, theories on adjuvants and tank mixes as well as more novel approaches, the UK needs a representative on the EUFRIN group, which is at the forefront of thinning research in Europe;
6. Experimental work to identify optimum use of combinations of chemical thinners - those currently available, likely to become available and novel treatments with and without adjuvants, under UK conditions;
7. Review longer term effects of mechanical thinning techniques on tree health – a study tour to gather information from regions where mechanical thinning has been used widely over several seasons;
8. Experimental comparison of mechanical thinning equipment - the Darwin system, the BAUM/Bonner and others available on the market for different growing systems;

9. Investigate the potential of shading as a thinning strategy in the UK;
10. Investigate spray application techniques – assess if chemical thinning using products such as ATS, which require good contact with the centres of flowers, can be improved through changes in volume or nozzle technology;
11. Update the HDC Apple Best Practice Guide thinning sections based on the findings in this review and develop this into a smart phone friendly format. Provide timely updates with links to best practice advice at key thinning milestones through the season.

Financial comparisons

A cost comparison of currently utilised methods has been produced as part of this review and is detailed below. This excludes machinery costs and assumes that the thinning efficacy of all approaches is adequate. This is not commonly the case and further applications or greater amounts of hand thinning may be required.

Scenario	Method	Frequency	Number of people-hours required to thin 1 ha	Total cost per ha
1 - Use of chemical blossom thinner followed by hand thinning as required	ATS	3	0.5	**£1,657**
	Hand	2	175 (125 hrs for first lot of hand thinning and 50 hrs for second lot)	
2 - Use of a mechanical blossom thinner followed by hand thinning as required	Mechanical	1	1.25	**£1,291**
	Hand	1	150	
3 - Purely hand thinned	Hand	2	250 (assuming each hand thin took 125 hrs)	**£2,125**
4 - Combined chemical blossom and fruitlet thinner	ATS	1	0.5	**£689**
	BA	1	0.5	
	Hand	1	50	

SCIENCE SECTION

Introduction

Fruit trees regularly set excessive numbers of fruit in relation to the tree size and leaf area. Potentially this results in small, low value fruit which often has a poor storage potential or is unmarketable and ends up going to juice or waste. Flower and fruit thinning is used to help prevent the trees from producing excessive numbers of small fruit to allow the remaining fruit to reach a greater size and be retained by the tree until harvest. It also makes the remaining fruit easier and cheaper to pick and easier and cheaper to grade. Recent research has even shown that fruits from thinned trees also have a higher concentration of polyphenols, benefitting human health and nutrition (Stopar, Bolcina et al. 2002).

Approaches to fruit thinning vary from orchard to orchard and year to year, based on cropping history, orchard system and personal choice, with combinations of mechanical, chemical and hand thinning at flower or fruitlet stages, along with removal of the sites of floral bud development during winter pruning. All approaches have their advantages and disadvantages. Understanding and optimising current approaches and finding effective, inexpensive novel techniques are of vital importance for top fruit production. Furthermore, understanding how different and new approaches may affect other aspects of fruit quality (other than size and yield) such as dry matter content, fruit firmness and storability could also present very real benefits. For example, with the area of Gala continuing to rise in the UK, extending the marketing period of this variety is very desirable for cost effective marketing of an increasing tonnage of fruit.

There was therefore a need to review and collate basic physiological tree fruit research as well as leading overseas research on tree fruit thinning, to understand further how these methods affect trees and fruit more generally and to identify new strategies or combinations of approaches to flower and fruitlet thinning which can be trialled for UK orchards.

Objectives

The overall aim of this project was to conduct a review of tree fruit thinning, primarily focusing on apple crops, but information from other tree fruit types was included where relevant, from the UK and overseas. The review has identified potential areas of development of thinning practices in the UK which are economic and ensure optimal tree and fruit quality.

The specific project objectives were to:

1. Identify the gaps in our understanding of the physiology of fruit setting, fruit drop and the control and management of these in relation to the different fruit thinning techniques to optimise fruit quality, size, cropping potential and also other aspects of fruit quality, particularly in relation to fruit storage;

2. Review and collate relevant UK and overseas information using scientific literature, interviews with relevant stakeholders and researchers and other relevant UK and international sources regarding new technologies and or approaches to the science and practice of optimising fruit thinning;

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4. Provide a simple cost comparison of novel approaches or combinations of approaches if accurate information can be sourced.

Understanding the basics

Fruit set and fruit drop

Fruit set is determined by many factors including pollination, availability of water and nutrients, orchard practices (such as pruning, cultivation, fertilisation and plant protection product use), weather and soil conditions (MacDaniels and Heinicke 1929). It is important that these practices are optimised to ensure that good fruit set is achieved.

Additionally, it is important to control factors that can lead to fruit drop. Flowers and fruits often thin themselves naturally during certain periods. Generally flowers that are not pollinated turn yellow and drop off just after flowering however, it is possible in certain varieties to achieve satisfactory fruit development without all ovules being fertilised and therefore containing seeds (pips). Many varieties will however develop misshapen fruit unless most of the cells of the core contain at least one fully developed seed (Ministry of Agriculture Fisheries and Food 1972). Small immature fruits or fruitlets containing insufficient complement of seed often drop naturally during the June drop (MacDaniels and Heinicke 1929, Ministry of Agriculture Fisheries and Food 1972). There is currently mixed opinion on the necessity of good pollination, certain varieties such as Jonagold can grow well formed fruit without seeds and are being increasingly planted with few pollinator trees. There is however some concern that the absence of seeds can affect the trees draw of nutrients and parthenogenetic fruit (seed-less fruit) may shed later than fruit with seeds, thus affecting thinning strategies and harvest planning (Project steering group personal Communication on 11 November 2014).

The seeds that have developed in the fruit produce auxins and gibberellins, both of which are important growth regulators in the development of fruit. The amount of auxin that is exported from a fruit or the apical meristem of a shoot determines the competitive power of that part compared to others. The fruit or shoot that produces most auxin is dominant and will draw most assimilates (Schroder, Link et al. 2013). Ethylene, a gaseous growth regulator, is also positively linked to the self-regulatory process of leaf and fruit abscission (Dal Cin, Danesin et al. 2005, Greene, Schupp et al. 2011). Ethylene originates in the flesh and seed in response to physiological changes and is translocated to the pedicel and acts to induce fruitlet abscission (Arakawa, Akagi et al. 2004, Dal Cin, Danesin et al. 2005). The balance between ethylene and auxins in the abscission zone determines whether a fruit will drop (Maas 2014). Ethylene has also been shown to play a role in chemical and mechanical thinning, through the evolution of ethylene in response to tissue damage (Dal Cin, Danesin et al. 2005, NP Seymour Ltd. n.d.).

Competition for water and soil nutrients occurs between young fruits, shoots and expanding leaves (MacDaniels and Heinicke 1929). If the young fruits fail to gain sufficient water and nutrients, including nitrogen, especially during the period when abscission is more likely, then they will be shed from the tree. Any conditions that restrict nutrient uptake by the roots may well be responsible for premature fruit drop (MacDaniels and Heinicke 1929).

In addition to soil nutrients, developing fruits also require large amounts of carbohydrate which is synthesised by the leaves to strengthen fibrous tissues in the fruit and increase the thickness of the cell walls. High levels of carbohydrates result in fruit held more firmly to the cluster base and fruit less likely to respond to stimuli that cause fruit abscission. Much of the carbohydrate that is used for the early growth of roots, leaves and for the initial stages of fruit development is stored in plant tissues during the previous year, hence why limited carbohydrate supply in one year can lead to a poor fruit set in the following year (MacDaniels and Heinicke 1929). Factors that may cause injury, such as pests and disease, will also contribute to abscission, e.g. codling moth.

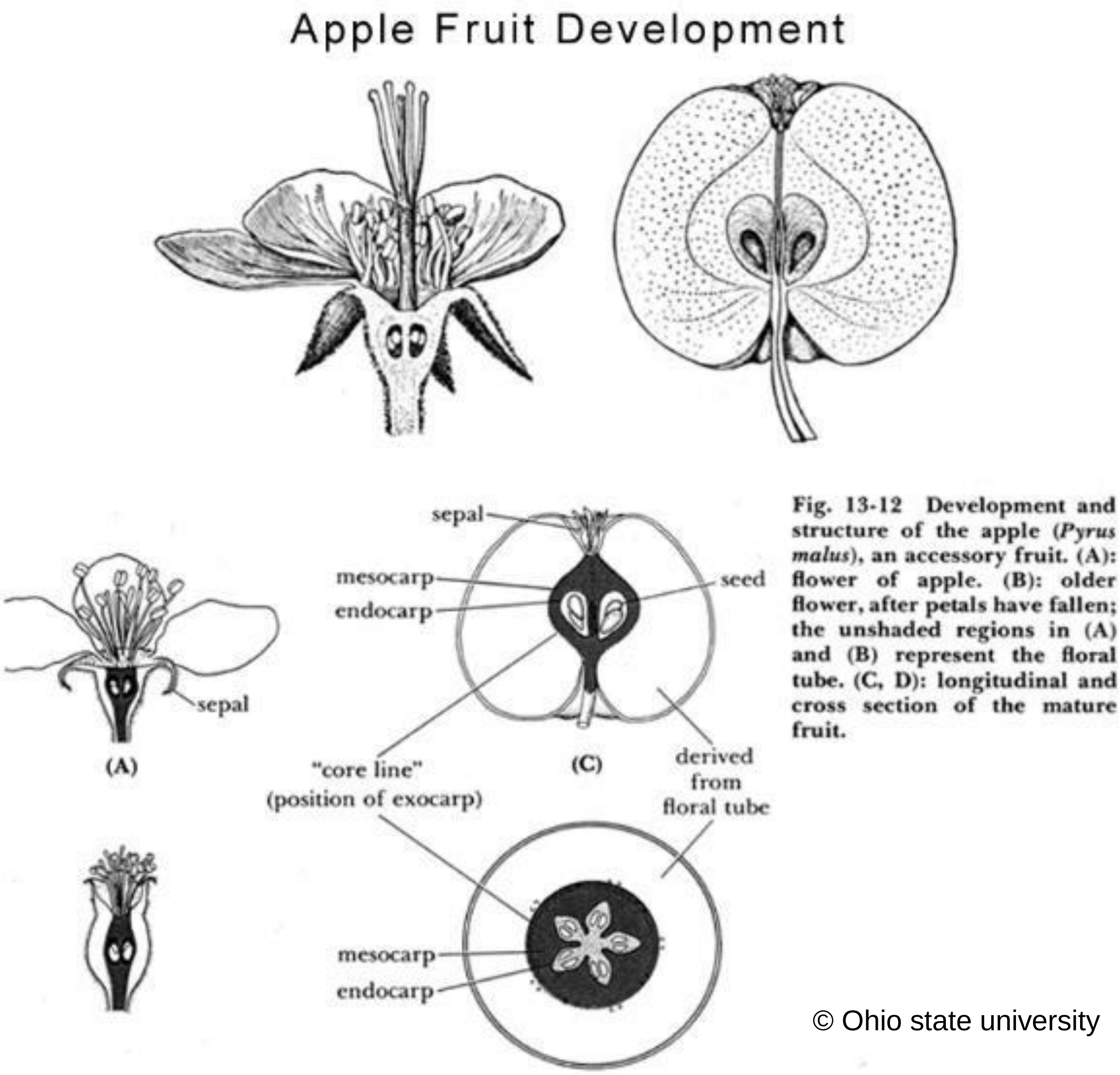

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Figure 1: Diagram of the development and structure of apple

Source:www.biosci.ohiostate.edu/~plantbio/osu_pcmb/pcmb_lab_resources/images/pcmb643/FLOWERSFRUITS_apple_fruit_development.jpg

Fruit quality in apples

Fruit size is strongly correlated with profit, however quality parameters are also critical. Quantifiable factors of quality include skin finish and blemishes, flesh firmness, dry matter content (DMC), colour, shape, juiciness, sweetness (Brix), sugar/acid ratio and storability (including nutrient composition).

Firmness

Flesh firmness (FF) is a primary measure of apple fruit texture and is the main determinant of eating quality of apples. Firmer apples are considered to be of better quality than softer ones (Harker, Jaeger et al. 2007). Many markets now have minimum quality standards of FF and soluble solids concentration (SSC) for apples, to ensure that fruit is of a consistent high quality and that it can be delivered to the consumers over a long marketing period (Johnston, Hewett et al. 2002). Trials in the 1980's at EMR suggested that thinning Cox increased fruit firmness (Horscroft and Sharples 1987).

Dry matter content

There is also strong correlation between the DMC and the quality of apples since DMC describes the processes responsible for texture, carbohydrate status and flavour potential of fruit (Palmer, Harker et al. 2010). This relationship is reviewed extensively in HDC Project TF 222 (Biddlecombe 2014) which suggested that fruit thinned earlier was larger and had higher dry matter and therefore improved storage potential (Perring and Pearson 1986).

Carbohydrate and acid content

Carbohydrates are produced by the leaves (the source) via photosynthesis and transported to the roots, shoots, trunks, branches and fruits (the sinks) (Monteith and Moss 1977). Crop load is correlated to soluble solids and titratable acid levels in fruit (Link 2000) and thinning therefore improves taste (Schumacher and Stadler 1987). Carbohydrate balance is also an important factor in natural fruitlet abscission and the readiness of fruit to abscise after thinning (Lakso, Greene et al. 2006). Fruit at the 8 to 15 mm size stage are easily thinned because the carbohydrate demand by the developing fruit and other sinks often exceeds the supply that is provided by photosynthesis, particularly at low light intensities. Photosynthesis inhibitors, such as the herbicide active metamitron, work by reducing the carbohydrate available to the developing sinks and thus increasing abscission (Greene, Schupp et al. 2011).

Colour

The light distribution within the canopy affects fruit colour (Rom 1991). In experiments carried out on Jonagold apples, Stopar, Bolcina et al. (2002) found that the fruit from low cropping trees had more red blush. Similarly, Embree *et al*. (2007) found that Honeycrisp apples from trees with high crop loads had greatly reduced coloration. Researchers have suggested that poor colouration may be the result of less assimilate being available to each fruit (Robinson and Watkins 2003, Wright, Embree et al. 2006). Poor fruit colour can also come about due to shading within the canopy, therefore thinning directly improves this aspect of fruit quality.

Fruit shape

Fruit shape is another measure of fruit quality. Reducing crop load by thinning improves the likelihood that fruit will grow evenly and round. This is because the calyx lobes are flattened and the calyx end is able to grow round (Link 2000).

Storage

Fruit size affects firmness and post-harvest softening in apples, however, the relationship varies. Studies have shown that small fruit are firmer than the larger fruit at harvest and after storage (Harker, Stec et al. 1997). Another study has shown that when fruit was harvested at an early stage of maturity, fruit size showed no effect on any part of the softening curve of apples stored at 0.5- 3°C, however when fruit was harvested at a later stage of maturity, the smaller fruit appeared to soften more slowly than the larger fruit (Johnston, Hewett et al. 2002).

Researchers have attempted to relate fruit firmness with biophysical properties found in different sized fruit, however there has been limited success. For example, Goffine, Robinson et al. (1995) found that in Empire apples there was a positive correlation between fruit size and cortical cell number but found no relationships with cell packing and intercellular space. Goffine et al. also found with Royal Gala apples that larger fruit had lower FF, larger cells, less cell packing and more intercellular airspaces than smaller fruit. This could indicate that there are no consistent relationships or alternatively, that there are varietal differences or other external factors.

Careful management of tree nutrition is critical to ensure adequate growth and allow cropping, however nutrient supply also directly impacts upon fruit storage potential and eating quality. Nitrogen is the most widely taken up nutrient, as with almost all plants, however excess nitrogen does not provide a yield benefit and has been shown to reduce blush and hasten breakdown and rotting (Station 1983). High levels of nitrogen and potassium applied to fruit have also been shown to increase the disorders bitter pit and core flush (Sharples 1980). Excess potassium levels can also cause other adverse effects in store and could lead to magnesium deficiency. Phosphorus deficiency is associated with flesh breakdown (HDC Apple Best Practice Guide 2014). Calcium is critical for fruit firmness through strengthening plant cell walls and reducing the incidence of bitter pit (Perring 1986). Low magnesium in fruits may induce flesh breakdown in stored fruit whilst excessive levels increase susceptibility to bitter pit and related disorders. Boron deficiency, although rare, can cause serious corking (HDC Apple Best Practice Guide 2014).

Through the course of this review few references were found looking specifically at the effects of thinning methods on apple nutrient composition. Therefore a detailed review of how nutrient composition of fruit is affected by thinning method would enable links to effects on storability to be drawn as there is a large body of research on fruit nutrient composition and storage ability available.

The effect of crop load on fruit quality

Trees with higher crop loads bear smaller fruits than those with lower crop loads. Apples from trees with higher crop loads also tend to have lower soluble solids content, lower titratable acidity, reduced flesh firmness, increased sunburn and altered background colour (Johnson 1992, Johnson 1994, Goffine, Robinson et al. 1995, Henriod, Johnston et al. 2007). Negatively, reducing crop load can also decrease yield per tree and increase the incidence of bitter pit (Henroid et al., 2007).

Many studies have demonstrated a relationship between crop load and fruit firmness. Royal Gala apples from trees with lower crop loads were found to be 10% firmer than trees with higher crop loads at harvest (Volz, Harker et al. 2004). Flesh firmness of Honeycrisp apples decreased as crop load increased, regardless of pre-storage treatments and storage environments (Delong, Prange et al. 2006).

In contrast, Cmelik, Tojnko et al. (2006) saw no significant effect of crop load on firmness at harvest of Fuji apples. In Jazz apples, larger fruit were slightly firmer than the smaller fruit at harvest but not after storage. Fruit firmness was influenced by dry matter content. Saei *et al*. concluded that variation in fruit firmness at harvest and during storage was influenced by processes that affect fruit dry matter content during fruit development (2011). Therefore, crop load appears to be an important factor in influencing dry matter content of fruit at harvest and during storage.

Optimum crop load

An understanding of optimal crop load is important when determining the extent to which thinning should be carried out. Optimal crop load is dependent on tree spacing. Factors affecting optimal crop load are reviewed in the HDC Apple Best Practice Guide where target fruit numbers based on tree spacing are detailed for common UK varieties. Most UK crop load information is based on research carried out in the 1970's on Cox at Long Ashton Research Station (LARS). To determine the optimum crop for Cox on MM106 trials were run over six years, hand thinning the same trees each year to five different target loads (18, 15, 12, 9 and 6 fruits/cm^2). The variability in cropping of un-thinned trees compared with the 6 fruits /cm^2 cross sectional area of trunk treatment achieved cumulative yields almost as high as the un-thinned trees and fruit size was much improved (LARS 1983).

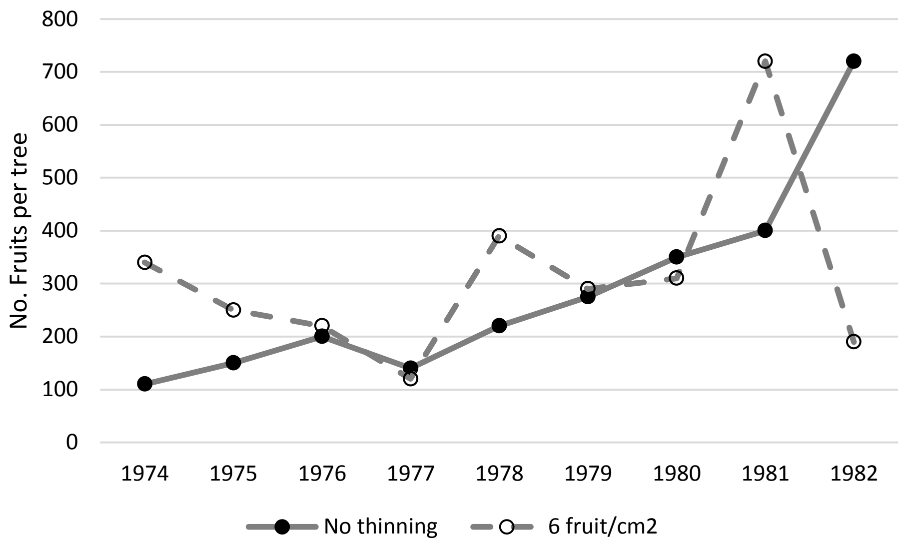

Figure 2. Number of fruits harvested (+ windfalls) per tree per year between 1974 and 1982 (LARS 1983)

More recently, optimal crop loads for the apple variety Jazz have been assessed. Jazz produces medium size fruit, similar to Royal Gala. It has been found that fruit on spurs and terminals are significantly larger than fruit on one year old wood (ENZA 2006). ENZA have produced charts detailing the number of fruit to retain according to per cm² trunk cross sectional area (TCA) for each of the different root stocks used, for example; on dwarfing rootstock (M9, M26, Mark) there should be eight to twelve apples per cm^2 TCA Table 1. Semi dwarfing rootstocks (M793, MM106, and M116) should have only six to eight fruit per cm^2 TCA. Greater than twelve apples per cm^2 TCA causes problems with fruit quality, delays maturity, reduces flesh firmness and Brix levels and reduces return bloom (ENZA 2006).

Table 1. Crop loads for Jazz using trunk cross sectional area (TCA) - M9/M26/Mark rootstock

Trunk at 20cm above union		TCA (cm^2)	Fruit number per TCA				
Circumference (cm)	**Diameter (cm)**		**8**	**9**	**10**	**11**	**12**
			Total fruit per tree				
8	2.5	5.1	41	46	51	56	61
10	3.2	8.0	64	72	80	88	95
12	3.8	11.5	92	103	115	126	138
14	4.5	15.6	125	140	156	172	187
16	5.1	20.4	163	183	204	224	244

Methods to achieve optimum crop load

Reduction of number of floral buds by winter pruning

Winter pruning can be a valuable method of reducing the number of flowers that set on the trees and it can help lessen the need for expensive thinning operations later on in the season. It is an effective way to ensure that competition between flowers and fruits for the tree's resources is kept to the minimum, due to it being carried out early in the season (Webster 2002).

A challenge with this technique is that it lacks precision in terms of the number of flower buds left on the tree unless the winter pruning is carried out much later in the spring. Growers often consider it a high risk strategy because it is carried out before flowering and so there is still a risk of frost damaging remaining blossoms (Webster 2002). Long Ashton research in 1982 investigated three different pruning treatments on Cox to find out the effect of regulating the amount of fruit-bud to pre-determined densities. Results showed that the greatest number of large fruits came from trees pruned to five fruit buds per cm^2 cross sectional area of branch. This is explained by hard pruning in abundant years avoiding over cropping and little or no pruning before the "off" years. However excessive shoot growth hindered good colour development and therefore a compromise of 10 fruit-buds per cm^2 was recommended to give large well coloured fruits (LARS 1983).

Table 2: Long Aston Report 1982 – Effect on crop weight and fruit size of pruning Cox's Orange Pippin to 5, 10 and 15 fruit buds cm^{-2} cross sectional area (LARS 1983).

Target no. fruit buds cm^{-2}	**No. fruit buds tree $^{-1}$**		**Mean no. fruits tree^{-1}**			**Fruit weight tree^{-1} kg**
	Excessed removed	**After pruning**	**Total**	**Size <60 mm**	**Size >60 mm**	
5	293	348	469	353	116	42.1
10	187	684	507	434	73	41.1
15	80	1018	629	598	31	45.1

Inhibition of flower bud formation

Gibberellins are plant hormones that regulate and influence various developmental processes in plants. They are known to suppress flower initiation or cause early floral abortion if they are present in excessive amounts during the critical stages of floral development. It is believed that the excessive concentration of gibberellins produced by the seeds of fruits is one of the causes of biennial bearing (Webster 2002).

Synthetic gibberellins have been trialled in California to suppress excessive flowering. The gibberellins were applied to peach trees in the summer months when the flower buds were developing and the number of flower buds were significantly reduced (Webster 2002).

There are drawbacks however to this technique. It would be difficult to control the amount of flower buds left on the tree. It is also thought that the gibberellins applied may reduce the tree's ability to set fruit in the following season.

Preventing fruit set by flower thinning

Flower thinning can be achieved by removing a proportion of flowers at or close to the time when full bloom occurs, reducing the potential for pollination of the flowers or by the prevention of the set of a proportion of the flowers with chemical sprays. This strategy can be achieved by hand, chemicals or mechanically.

Reducing the potential for successful pollination could be achieved by reducing the numbers of potential pollinator plants planted within or close to the orchard or by reducing the activity of pollinator insects in the orchard (Webster 2002). Poor pollination however can lead to malformed fruit and excessive fruit drop.

Chemicals can be used to prevent a proportion of the flowers from setting fruits. This can work by preventing pollen germination and growth on/in the stigma and style or by stimulating the degeneration of the female ovules in the ovaries. With this kind of strategy it is important that the chemicals cause minimal damage to the developing spur leaves as these are particularly important for the development of fruitlets and ensuring sufficient uptake of calcium. Many thinning chemicals used on flowers work by desiccating the vital female organs of the flower (Webster 2002).

Reducing crop load by fruitlet thinning

Another technique for reducing crop load is by reducing the numbers of fruitlets on the tree at some point after fruit set (fruitlet thinning.) The fruitlets can either be physically removed from the tree (by hand or mechanical methods) or fruit drop can be stimulated by chemicals. The removal of fruitlets by hand is the most accurate method but is extremely costly (Webster 2002).

Control of pre-harvest drop

Pre-harvest drop is the fall of nearly ripe fruit just before it is time to harvest. The extent of pre-harvest drop varies between varieties and from season to season due to weather conditions. If the apple trees experience a period of warm weather prior to picking, especially if they also experience cold nights at this time, they will often drop a large amount of fruit. Trees with a high supply of nitrogen will drop more fruit than those with less nitrogen (Ministry of Agriculture Fisheries and Food, 1972).

Current thinning methods

Fruit thinning is carried out by growers to improve the quality of apples being produced. Unfortunately however, there is no one method that suits all varieties and orchards. Thinning can be done over a fairly wide time period from bloom until the fruits have grown to above 18mm in diameter (Greene and Costa 2013). Thinning techniques include thinning by hand, chemical application and mechanical devices.

Hand thinning

Thinning by hand is regarded as the most precise method for tree fruit thinning. It is the most reliable way of achieving the required crop load and fruit size. In UK apple orchards staff using the conventional hand thinning method are taught to thin fruitlet clusters down to singles or doubles depending on crop load, as early as possible at the fruitlet stage to avoid competition between fruit and promote flower bud initiation for the following crop. Trials carried out at East Malling in 1997 on semi-mature trees of Royal Gala on M9 rootstock showed thinning at or before the 12 mm fruitlet is beneficial (Webster and Spencer 1998)

Table 3. Effects of different timings of hand thinning Royal Gala trees in 1997.

Treatment timing of hand thinning	No. fruits/tree	Weight of fruit harvested/tree (kg)			
		Total	>65 mm diameter	>70 mm diameter	% of total 65 mm diameter
None (control)	235	18.6	1.4	0.1	8
Full bloom	52	7.8	6.1	2.6	78
Late initial set	80	10.9	8.0	4.4	73
12 mm diameter	100	12.6	5.9	2.7	43
18 mm diameter	84	9.5	2.8	0.2	29
24 mm diameter	83	9.1	3.3	0.8	36

American researcher Steve McCartney (2011) has suggested that this conventional method will result in a wide range of fruitlet sizes remaining on the tree due to the fact that this method does not focus on the fruitlet size. He developed the “Size Thinning Method”, which ensures that fruitlet size is the primary criterion for deciding which fruit to remove. This should mean that the fruit remaining is of a more consistent size compared to conventional methods. The Size Thinning Method has been trialled in America and was found to result in a narrower range of fruit sizes and a higher than average size compared to the conventional method of hand thinning (Schmidt, Auvil et al. 2011). In practice in the UK a combination of these approaches is used.

Chemical thinning

Chemicals that damage flower parts and/or cause stress in the whole tree can reduce the number of fruit on a tree. Widely used in the UK and around the world, chemical thinning agents are considered the most critical component of a thinning strategy. The efficacy of chemical thinners varies considerably between season, crop and orchard. Specific factors affecting efficacy include firstly factors relating to the tree's sensitivity such as previous yield, crop growth stage, bloom density, initial set, leaf area, leaf function, temperature, sunlight, tree vigour, etc. and secondly factors relating to the spray application such as concentration, temperature, humidity, coverage, drying condition, cuticle thickness and composition, etc. (Lakso, Robinson et al. 2007).

Worldwide, the chemicals which are most commonly used to thin apples at bloom are 2–chlorophosphonic acid (ethephon) and ammonium thiosulfate (ATS). The auxin, naphthalene acetic acid (NAA) and the cytokinin, 6- benzyladenine (6-BA) are the most commonly applied chemicals at the fruitlet stage (Greene and Costa 2013).

Ammonium thiosulphate (ATS)

In the UK ATS is the most commonly used chemical thinner for apples. ATS is applied at flowering and works in two ways; firstly by desiccating stigmas and styles within the flowers when applied to newly open flowers prior to pollination therefore preventing pollination and secondly by damaging foliage - this causes ethylene production which induces further fruit drop. In any one cluster of flowers it is unlikely that more than 30% of the potential blooms will be affected by a single application of ATS. ATS effectiveness is dependent on weather conditions, timing, spray coverage (as ATS needs to have direct contact with the centres of flowers and very newly opened flowers to be effective) and application rate. Studies have also shown that it can enhance the efficacy of post bloom thinners (Hampson and Bedford 2011). Some growers feel that current formulations are less effective than they once were.

The efficacy of ATS increases as temperatures increase, however in humid conditions phytotoxicity to spur leaves increases (Webster 2002). ATS application should target the newly opening flowers because flowers sprayed at pink bud or earlier may be damaged but still go on to set fruit (Webster 2002). Table 4 details some guidance on ATS spray concentration and volumes and the HDC Apple Best Practice Guide contains further variety specific guidance.

Poor results with ATS have been reported in older orchards with more complex canopies as it is harder to achieve good contact with the centres of flowers with conventional spray techniques (Project Steering Group personal communication on 11 November 2014). Investigation into spray techniques and nozzle technology could therefore help to optimise use of ATS.

Table 4. HDC apple best practice guide - Guidance on ATS concentrations and spray volumes as influenced by the temperatures and humidity at the time of spraying (HDC)

Relative Humidity (%)	**Temperature ^{0}C**					
	10-15		**15-20**		**20+**	
	ATS %	**Litres/ha**	**ATS %**	**Litres/ha**	**ATS %**	**Litres/ha**
>95	1.0	200-400	1.0	300-500	1.0	300-500
85	1.0	300-500	1.5	400-600	1.5	400-600
<80	1.0	400-600	1.5	600-800	1.5	800-1000

6-Benzyladenine (BA)

More recently, BA (Exilis, MaxCel and Globaryll 100) has been approved for use in the UK. Although data from North America and continental Europe shows that BA can be a very effective thinner (Dorigoni 2006), it requires continual warm temperatures (minimum 18°C) at the time of application and for 2-3 days after application, which often does not occur in the UK when the crop is at the appropriate stage for treatment (Aelbrecht 2014). The added difficulty is that if it is effective then the fruit can take up to a week to drop, meaning hand thinning activities and planning for harvest are delayed. Thus far up-take of BA in the UK has been low, however its use is expected to increase as growers and consultants become more experienced in how to make it effective and how to use it in conjunction with other chemicals, adjuvants and mechanical thinners.

BA is considered to be a mild chemical thinner and works on only part of the fruit cluster. However the mode of action has not been studied as extensively as other chemical thinners. Greene *et al*. (1992) showed that the application of BA stimulated ethylene production in both leaves and fruits and the rate of ethylene increased with the concentration of BA applied. This research also suggested that BA might reduce the supply of sugar to the fruit. Yuan (1998) observed that net photosynthesis was inhibited by 10 to 15% by BA application and leaf carbohydrate levels were also reduced. Yuan concluded that BA thinned by stimulating dark respiration (i.e. the release of carbon dioxide without the presence of sunlight) and thereby reducing the supply of carbohydrate to the fruit (Yuan 1998).

The recommended application stage of BA is 7-15mm, optimally 10-12mm, but suitable weather conditions should be the driving factor as long as the fruitlets are within the optimum application stage. The 2013 UK season was characterised by a cool spring and as such, trials with BA (Exilis) yielded mediocre results. However, in trials conducted by the manufacturer in various sites across Europe, there were good results for Exilis when used in tank mix with NAA and when used in sequence with either ATS, ethephon or the use of Darwin mechanical thinning at the flower stage (Aelbrecht 2014). These trials included the apple varieties Gala, Fuji, Golden Reinders and Elstar.

Ethephon

Ethephon is a commonly used chemical thinner in Europe. In the UK it is not available as a thinner but can be used in apples to encourage fruit maturity to manipulate harvest. It is hypothesized that ethephon is absorbed by the tissues, which then hydrolyse it to release ethylene, which can induce the abscission of leaves and fruitlets (Dennis Jr 2000).

In order for ethephon to be reliable it needs to be applied when temperatures at the time of application and for one to two days afterwards are 15°C or above. Generally, as the temperature increases the efficacy of ethephon increases linearly, however, it is difficult to determine an optimum timing and concentration as there are several other important variables to consider that factor into the effect it has as a thinner. These include relative humidity where efficacy increases with humidity. Extended periods of high humidity can lead to over thinning so humidity at application followed by a period of drying after application is key.

Ethephon also has markedly differing effects on different varieties, it has not been possible within this review obtain tables detailing rates for different varieties but if this information is supplied by our German contacts it will be submitted to the HDC subsequently. It has also been suggested that ethephon works best when the water it is dissolved in is slightly alkaline (Webster 2002).

1-naphthalene acetic acid (NAA)

NAA is a synthetic auxin and it varies in terms of its efficacy as a flower/ fruitlet thinner. There is no UK approval for the use of NAA as a chemical thinner. The mode of action of NAA is unclear as various studies have suggested different mechanisms (Murneek and Teubner , Luckwill 1953, Marsh, Southwick et al. 1960, Batjer and Thomson 1961, Dennis 1970, Frank and Dennis 2002). Efficacy of NAA depends on the chemical formula, concentration and the date of treatment (Agusti, Juan et al. 2000). When fruit undergoes the cell enlargement stage, NAA stops working as a thinner and switches to working as a fruit size enhancer (Reig, Mesejo et al. 2014) without affecting the number of developing fruits (Amorós, Zapata et al. 2004). Industry intelligence suggests that a chemical company is pursuing approval for NAA in the UK and is currently running trials, however it has not been possible to gather further information on this to date.

Mechanical thinning

Mechanical thinning is rising in popularity, particularly in Continental Europe and North America and is considered a viable alternative to other thinning methods. It does not have the same level of dependence on weather that chemical thinners do and is less expensive than extensive hand thinning. The mechanical options that are currently available around the world include the Darwin String Thinner, the Bonner thinner, the drum shaker thinner and various types of hand held thinning equipment.

Although well developed within Europe, and particularly around Lake Constance where the technique was developed, currently, most UK growers are at an experimental stage with mechanical thinning. As such, this topic will be covered in depth in the “novel approaches to tree fruit thinning section” later in this report. Concerns have been raised with regards tree health effects of the damage caused to trees and potentially ecological effects to pollinating insects and wildlife.

Influences of thinning method on fruit and tree attributes

Effect of thinning timing

The timing of flower/fruitlet removal is crucial and by extension, as various thinning methods are used at various timings, it is reasonable to assume that differences in fruit quality based on the timing of a particular thinning method could be achieved. Thinning carried out within a few weeks of blossom has the greatest effect in terms of reducing any tendency to biennial bearing (Ministry of Agriculture Fisheries and Food 1972). Early thinning reduces competition from very early on, meaning that resources such as carbohydrates are not wasted on fruit that are going to be removed and so the remaining fruits can achieve their optimum size. The combination of reducing crop load to a low or medium level and early thinning was found to increase mean fruit size (by up to 20%) (Henroid et al., 2007).

Time of thinning had little effect on flesh firmness or acidity, however, an increase in stem-end russet at harvest and bitter pit after storage were observed with earlier thinning of Jazz apples (Henriod, Johnston et al. 2007, Saei, Tustin et al. 2011). This would be consistent with previous work on apple that has shown a similar relationship of an increased risk of expression of calcium-related disorders after storage as thinning severity increased (Link 2000; Figure 3).

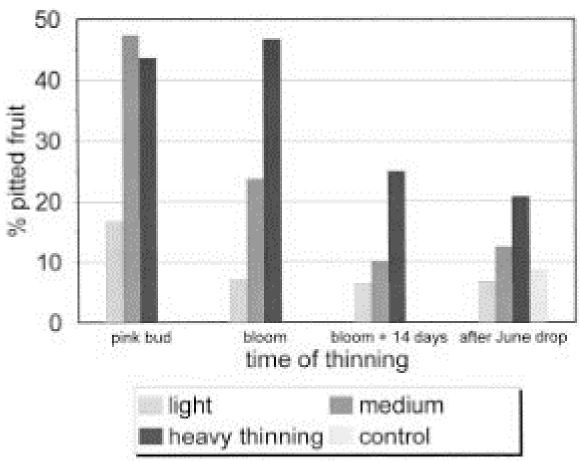

Figure 3. Bitter pit incidence in Boskoop as related to time and intensity of hand thinning (Link 2000).

Work has been carried out recently by HortResearch in New Zealand to assess the effect of flower and/or fruitlet removal. Removing all axillary flowers from one year old wood at full bloom from three year old Jazz apple trees on M9 rootstock had similar results to trees that were hand thinned in a commercial manner in early December (early summer in New Zealand) but produced fruit that was 44 g heavier in average count size from count 113 to count 88. This increase in fruit size was probably down to the early thinning and the selection of fruit on spurs and terminals in preference to axillary fruit on one year old wood (ENZA 2006).

This review found some reference to pre-harvest factors thought to influence fruit quality and texture at harvest and after storage, which included cultural practices that involve the timing and extent of thinning on fruit quality at harvest (Harker et al., 1997; Johnston et al., 2002a) and which requires further investigation. However the research suggests some complicated interactions between crop load, dry matter and firmness occur, with little mention of interaction with chemical thinners and or mechanical thinners. Therefore experimental work is recommended to supplement our understanding of how timing and levels and intensity of different thinning strategies may affect aspects of crop quality. This would help us to deduce what thinning strategies may provide most benefit e.g. in terms of timing, combination of several methods, or linking in with pruning approaches

Effect on fruit quality

The most obvious effect of thinning is on fruit size and number, however thinning also influences other aspects of fruit quality and texture, storability and tree health. Although there is ample literature on the benefits of thinning, the literature comparing the specific effects of thinning methods on fruit quality, storability and tree health is more limited.

Many studies have demonstrated the link between crop load and DMC which, in turn, affects fruit quality - reviewed in (Biddlecombe 2014). Fruit DMC includes compounds which affect flavour, structure and texture of fruit. It is believed that decreasing crop load positively affects fruit size, soluble solids, flesh firmness, dry matter and advanced maturity at harvest.

Chemical thinners

In studies undertaken in Poland on Gala apples, ATS applied at full bloom reduced fruit set and increased fruit size, especially the proportion of apples that were greater than 70 mm in diameter (Basak 2006). Other fruit qualities such as colour, SSC, FF and starch content were the same as the hand thinning treatment, suggesting that there was no effect of ATS on these parameters. When ATS was applied before bloom and BA (Paturyl 100 SL) was applied after bloom, fruit weight was the same as the hand thinning treatment, however size distribution was improved and FF and refractive index were higher, showing a benefit to potential fruit storability of using this chemical thinning regime. However, fruit colour was less intense than it was in the treatment with ATS alone (Basak, 2006). ATS was also applied during blossom and then followed up with NAA immediately after blossom. This treatment did reduce fruit set by around the same amount but it did not improve fruit quality parameters in the same way as ATS and BA did.

When ethephon was applied to Gala blossoms that were 80% open it caused the fruits to become larger and more uniform but also caused a slight flattening (Basak, 2006). Basak found that when ethephon was followed up with BA after blossoming, the thinning rate did not increase, however the refractive index and firmness were higher than in the fruits treated with just ethephon alone (Basak, 2006). The best results were obtained when ethephon was followed up with a treatment of NAA - the fruit size, size distribution and marketable yield were about the same as hand thinning but the firmness and colour were better, again suggesting benefits of certain auxin based chemical thinners on quality.

Link conversely found that various thinning chemicals may retard fruit growth. ATS and NAA for example have both been shown to limit fruit growth immediately after application (Link, 2000) whereas BA, even in the absence of fruit thinning, increased fruit size (Green et al. 1990; Basak, 1996).

Link (2000) has also demonstrated a link between thinning chemicals and russeting, showing that both BA and ATS resulted in an increase in russeting in some varieties, however these trends are not statistically significant. Fruit symmetry on the other hand, was not influenced significantly by different thinning chemicals - Link, (2000). Work carried out on Golden Delicious in Croatia identified differences in fruit metabolism between fruit thinned by hand and by chemical means (Jemric, Pavicic et al. 2003) (NAA) with clear differences being shown in fruit ripening, maturity and nutritional characteristics. The interactions described are complex but show both positive and negative fruit quality characteristics of chemical vs hand thinning techniques, such as increased fruit firmness but also increased weight loss with NNA after storage. These interactions contradict other research and a key conclusion from this work was that these interactions require further investigation (Jemric, Pavicic et al. 2003, Jemric, Pavicic et al. 2005)

Mechanical thinning equipment

Solomakhin et al. (2012) found that mechanical thinning with a 'BAUM' style thinning device led to an improvement in fruit quality compared to an untreated control and comparable quality to a fully hand thinned treatment. This was due to an increase in soluble solids (taste), acidity, fruit size, fruit with advanced ripeness and also better red fruit coloration, associated with a higher (healthy) anthocyanin and chlorophyll content. The best engineering results were found with 360 rpm with both 6 km/h and 7.5 km/h vehicle speeds. This technique resulted in a compromise between minimal tree damage and reduced crop of apples of good quality, in terms of colour, taste and fruit size (Solomakhin, Trunov, Blanke, & Noga, 2012).

Seehuber et al. (2014) carried out an experiment to improve fruit quality traits by the use of mechanical thinning, using a new mechanical device developed at the University of Bonn. A vertical mast supports three horizontal rotors, whose vertically rotating arms remove excess flowers. The experiments were carried out on ten year old spindle trees of the apple variety Gala Mondial near Bonn in Germany. The two rotor speeds used were 360 rpm or 420 rpm at 5 or 7.5 km/h tractor speed.

The method of combining mechanical and manual thinning improved the proportion of well coloured fruit, which was probably due to the selective removal of shaded fruits from the inner tree canopy. Mechanical thinning improved fruit firmness in comparison to the untreated control (i.e. no thinning) (Seehuber et al., 2014).

Effect on storability

There are many factors which affect the storability of apples, some of which appear to be linked to thinning. Calcium content, for example, is an important component of storability as it relates to bitter pit, internal breakdown and other disorders. Thinning in general has been shown to increase the incidence of bitter pit (Link 2000), with more severe thinning resulting in even higher incidence. Thinning has also been shown to increase phosphorus, potassium and nitrogen content of apples (Link 2000) however there have been conflicting reports on the direct effect that this has on storability (Johnson, Marks et al. 1987, Link 2000). Guzewski showed in his investigation of mineral content and storage ability of apples treated with chemical thinners and plant growth regulants (PGRs) that fruit from the trees treated with NAA and carbaryl had a higher content of calcium in comparison to the control. Fruit of Gloster from the paclobutrazol treatments, which caused a strong retardation of elongation growth, had the best mineral composition and were less affected by storage disorders (Guzewski 1993).

This, along with the work by Jemric (2005) highlighting conflicting differences in fruit firmness and maturity, demonstrate complex mineral and ripening effects of chemical thinners on fruit, which can effect storage.

Effect on tree health

No specific literature has been identified which suggests that specific thinning methods will impact on long term tree health. Through conversations with growers it has been suggested that the use of mechanical thinning devices, which physically damage parts of the tree, may lead to increased disease pressure (i.e. fireblight, canker and possibly scab) however this is not supported by the literature nor by first-hand experience. Mechanical thinning does cause major physiological effects on the whole tree as shown by the requirement to alter management strategies such as PGR use after application (Project Steering Group personal communication, 11 November 2014), therefore an understanding of longer term effects is required to ensure the process is not detrimental to fruit and tree health and quality.

Novel approaches to fruit tree thinning

Chemical thinners

Metamitron

Metamitron is a photosystem II inhibitor and is currently listed on Annex 1 and registered in the UK as an herbicide for use on beet crops, with off-label approval for various other horticultural crops. Metamitron was identified by the EUFRIN Thinning Group as a high-potential molecule for fruit tree thinning. The use of photosystem II inhibitors for fruit thinning is not a new concept. In 1990, 12 photosynthetic inhibitors from a range of chemical classes were tested for fruit thinning (Byers, Barden et al. 1990). Although these chemicals were effective in their ability to thin fruit they were not initially adopted commercially because of crop safety (Baur, Benz et al. 2004).

Initial studies evaluated photosynthesis inhibiting active substances as floral thinners but it has since been discovered that using these compounds (specifically metamitron) at a later fruiting stage (i.e. 8-30mm) eliminates unwanted plant damage (Baur, Benz et al. 2004). The import of assimilates ten to thirty days after flowering (i.e. through use of a photosynthesis inhibitor) can promote June drop (Maas 2014).

Metamitron has since been tested as a chemical thinning agent at various rates and timings (Dorigoni and Lezzer 2007, Deckers, Schoofs et al. 2010, Lafer 2010, McArtney and Obermiller 2012, McArtney, Obermiller et al. 2012, Eccher, Botton et al. 2013, Fernandes, Oliveira et al. 2013) and always produced promising thinning results.

The thinning effects of metamitron 350 mg L^{-1} (applied as a single and double application) at 6 to 8 mm and 12-14 mm fruitlet diameter, and ethephon 216 mg L^{-1} (applied at balloon stage) followed by Metamitron 350 mg L $^{-1}$ at 10 to 12mm were trialled on Elstar apple trees from 2006 to 2008. The trees were planted in 2002 and trained to a slender spindle (Lafer 2010).

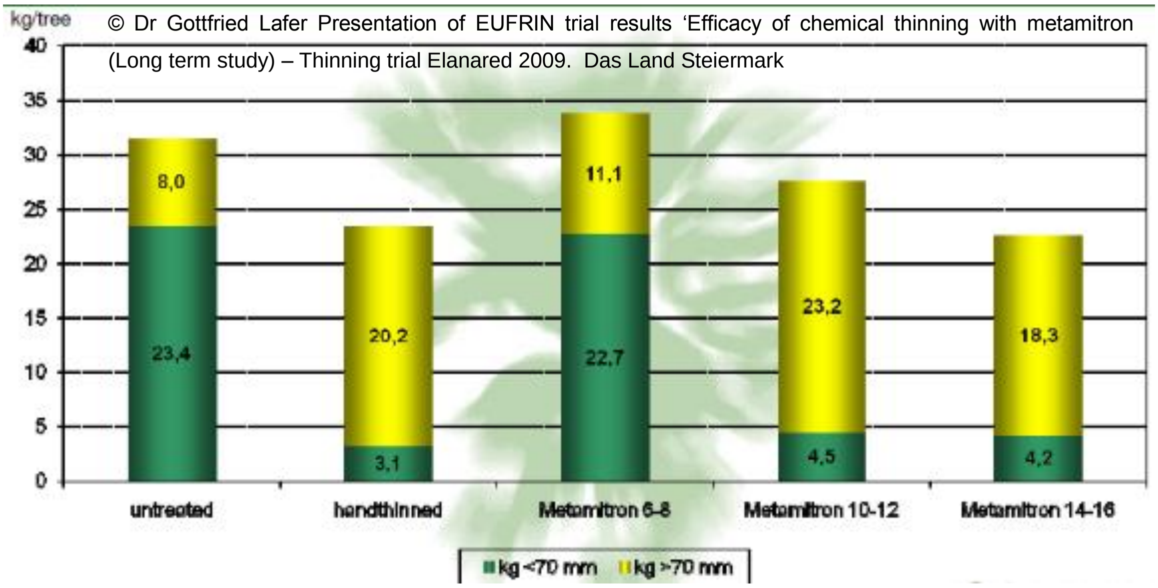

Figure 4. Metamitron thinning trial results – effects of metamitron applied at different fruitlet sizes compared with hand thinning (Lafer 2010)

The thinning efficacy of metamitron was dependent upon time of application. The repeated application of metamitron caused a reduction in fruit number and the fruit size was normally improved in relation to crop load reduction. Return bloom was found to link strongly to the thinning efficacy (crop load). In terms of safety, metamitron did not cause leaf injury when applied to thin fruitlets. Neither did it lead to pigmy fruits, fruit malformation, russeting or detectable residue levels in the fruit. Internal fruit quality improved with usage of metamitron according to the reduction of crop load. It was concluded that the dosage of metamitron needed to be adapted according to fruitlet diameter and / or light intensity in order to optimise its effect (Lafer 2010).

The normal window for application of chemical thinners occurs from bloom until three weeks after bloom, when the fruit reach an approximate diameter of 16 mm. After this, chemical thinning sprays tend to have no effect in terms of thinning (McArtney and Obermiller 2012). These researchers investigated the potential extension of this application window of thinning chemicals by testing metamitron and the ethylene precursor 1-amiocyclopropane carboxylic acid (ACC). The treatment of 350 mg L^{-1} Metamitron was found to reduce fruit number better than either the standard (carbaryl) or ACC treatment. They found the combination of metamitron and ACC showed effects after application to 25 and 33 mm fruit diameter in 2011 and 2012. Since the effect on thinning was greatest when metamitron and ACC were combined, this could suggest that the creation of a carbohydrate stress and the capacity to convert ACC to ethylene are both required in order to stimulate abscission of apple fruit larger than 18 mm in diameter (McArtney and Obermiller 2012).

A European patent has been granted for a formulation containing 50-400 mg/L metamitron for use on fruitlets at the 8-30mm fruit stage (Baur 2001). A new product containing a reduced rate of metamitron (150g/kg), specifically formulated for the thinning of fruit trees has now been approved for use in Italy and Belgium. A product label can be found at:

(http://www.salute.gov.it/fitosanitariwsWeb_new/EtichettaServlet?id=19460).

The product, called Brevis®, is manufactured by ADAMA (formally Makhteshim Agan). ADAMA is currently pursuing registration of this product in the UK and have carried out UK trials, yielding very promising results, for the past two seasons (Paul Fogg, ADAMA, personal communication 18 September, 2014). Currently the timeline for registration is unclear but it is hoped that the product will be available to growers by 2015/2016. This product however, like BA, is not effective on stone fruit. Due to the fact that this product is a photosynthesis inhibitor current research within the EUFRIN group is going into metamitron efficacy in relation to the amount of available sunlight, measuring the degree and duration of photosynthesis inhibition. The EUFRIN group is working with ADAMA (Makhteshim Agan) to develop a device to measure this. Further research is also going into linking the use of this device with the MaluSim carbohydrate balance model developed in the USA (described later in this review). The aim is to provide better advice concerning the dose of metamitron (Maas 2014).

Other novel chemicals

Other chemicals that have been used in trials recently and are showing potential include; sodium chloride, caustic salts, weak acids, lime sulphur, potassium bicarbonate and combinations of spray oils and lime sulphur (Washington State University, 2014, Johnson (2006)). Lime sulphur is registered in some European countries and has been tested on apple trees in Korea (Chun, Zheng et al. 2012). Triple applications of 1% lime sulphur significantly reduced the number of terminal and axillary fruits (Chun, Zheng et al. 2012). This product is effective on open flowers and needs to be applied as soon as flowers open and repeated applications are likely to be required. This product also has efficacy against mildew and scab and is therefore a very good option for organic systems (Scholten 2014). Sodium chloride (common salt) was shown to be an effective alternative to ammonium thiosulphate for thinning apple flowers in trials carried out at East Malling in 2005 and, with careful use as over thinning is possible, again would be potentially suitable for organic systems (Johnson 2006).

Tank mixes and adjuvants

With the exception of metamitron, few new promising chemicals are being identified as thinners. Ongoing research within EUFRIN and in other parts of the world are therefore focussing on the use of sequences of chemicals, tank mixes and adjuvants to optimise use of the chemistry available. Penn state extension service states that the addition of an oil based adjuvant boosts the efficacy of almost all thinners (Schupp 2013). Manufacturers' guidance on the use of wetters differs greatly, often as a result of actives being developed in warmer climates where efficacy is less limited. ATS however should **never** be tank mixed or combined with an adjuvant and application of other products to the crop is not recommended for two days after application due to potential phytotoxic effects (HDC Apple Best Practice Guide).

Basak's (2005) review of chemical thinning demonstrated the benefit of incorporating adjuvants to certain chemical thinners e.g. the incorporation of the adjuvants Atpolan 80 EC and Adbios 85 SL with standard rate NAA gave a comparable thinning effect to double rate NAA, and similar effects were shown with Torpedo II and BA. The use of these adjuvants/accelerators caused additional increases in fruit size. However in other trials BA plus the adjuvant Genapol caused over thinning. Combinations of ethephon at the beginning of bloom, and NAA or BA after bloom, and late thinning with the mixture of NAA and BA demonstrated an advantageous effect (Basak 2005).

Of these chemicals only ATS and BA are approved for use in the UK. Trials at EMR in 1998 showed a spray of ATS (0.5 or 1.0%) at full bloom, followed by a spray of BA (Perlan 100 ppm), all at high volume (1,000 litres/ha), showed some promise for thinning the variety Royal Gala (Webster and Spencer 1998). The combination of BA and auxins such as NAA has also been shown to increase the efficacy of BA (Maas 2014).

Mechanical thinning

Although not entirely novel, because mechanical thinning has been practiced worldwide and in the UK for a number of years, it has been included in this section of the report because many growers are still only at an experimental stage when using this technology. Unlike chemical thinning products, mechanical thinning is possible in all countries and, contrary to popular belief, the mechanical effect does not just act by damaging blossoms and removing buds, the thinning effect also comes from damaging leaves and the subsequent flush of ethylene production. This effect however is not consistent across all varieties so careful trials work is required (Scholten 2014). A range of different systems are available and these are described below.

Darwin string thinner

The Darwin String Thinner is the most extensively used mechanical thinning device. It consists of a central shaft with a single rotating spindle with cords that, once rotating, knock fruit buds, blossoms and leaves off the tree. In the UK, NP Seymour Ltd. first demonstrated the Darwin thinner in 2008 and since that time approximately 16 have been sold in the UK (Nick Seymour, personal communication, 3 September, 2014). The Darwin thinner is non-selective but tree shape may be important for successful use of this machine. A slender tree is preferred; trees with strong, thick branches may be over-thinned and hanging branches may be under-thinned (Poldervaart 2009).

The rotational speed, tractor speed and string configuration are all important factors for optimising thinning and, although multiple studies have been done to determine the best practice, results vary and some experimentation on farm will be necessary to obtain the best results. According to the German manufacturer of the Darwin String Thinner, thinning becomes effective with a rotational speed of 200 rpm but this speed must take into account the forward tractor speed as well (FruitTec 2011). Growers using the Darwin thinner are advised to thin 10 trees at 200 rpm, 8 km/h forward speed initially, then stop and assess results and adjust the forward speed if needed to obtain the desired results (Nick Seymour, personal communication, 3 September, 2014).

Figure 5. Example of the Darwin blossom thinner in action

Technical support is provided to those who purchase the Darwin thinner, however due to the specific nature of tree thinning growers are advised to experiment with the equipment to optimise how this technology works on their specific trees as published results vary greatly in the forward speeds and revolutions per minute. Small scale trials in the UK have concluded that a combination of mechanical pruning and mechanical thinning in a fruit wall system can reduce labour costs by up to £2,000/ha, encourage more consistent cropping and eliminate biennialism (Tompsett 2009). In four year old Cameo apple orchards the yield following Darwin thinning was greater than that of the hand thinned controls (Tompsett 2009).

In a study comparing rotational speeds of a Darwin PT-250 on five year old Buckeye Gala/M9 apple trees it was found that high speeds (240-300 rpm) resulted in the greatest reduction of blossom density (blossom clusters per limb cross-sectional area) and number of blossoms per spur but also significantly reduced spur leaf area and yield (Kon, Schupp et al. 2013). In this study, speeds of 180-210 rpm were considered optimal, based on thinning response and injury to spur leaves, but the resulting crop load reduction was too low in years of heavy fruit set and the authors' view was that this form of mechanical thinning would be best in combination with other thinning techniques.

A summary of multiple trials preformed in Ontario, Canada found that optimal settings in a high density spindle system were tractor speeds of 4-6 mph, spindle rotation of 220-240 rpm (Slingerland 2009). In addition to those already discussed, other factors are also important in determining the success of Darwin thinning. Time of day, due to moisture in the tree, (Nick Seymour, personal communication, 3 September, 2014) and how closely the equipment is positioned to the centre of the tree (Kentish grower, personal communication, 27 August, 2014) have both been identified as important factors. The Darwin String Thinner has also been tested and is being commercially used in other tree fruits such as peach and plum (Auxt Baugher, Ellis et al. 2010, Auxt Baugher, Schupp et al. 2010, Miller, Schupp et al. 2011, Reighard and Henderson 2012).

BAUM thinner

More recently, a new machine, the BAUM (previously Bonner) thinner, has been developed at the University of Bonn, Germany (Damerow and Blanke 2009). The BAUM thinner is similar to the Darwin thinner in that it utilises rotating shafts with cords to remove fruit buds and blossoms from the tree. Unlike the Darwin however, the BAUM thinner consists of three horizontal rotating shafts that can be adjusted vertically and horizontally to reach into the tree canopy at various angles. The BAUM thinner can be more precise than the Darwin thinner because there is more flexibility in the positioning of the shafts. Experiments from 2005-2007 showed that flowers nearer the tree trunk could be targeted using the BAUM thinner and that rotational speeds of 300-420 rpm, coupled with forward tractor speeds of 5-7 km/h were the most effective (Damerow and Blanke 2009).

In other trials the BAUM thinner reduced the number of apples from 18 per branch to eight, using the strongest method of thinning (420 rpm, 5 km/h). It was found that the natural June drop after mechanical thinning had taken place was the same as it was for the un-thinned control. Fruit mass increased by 20 g to 48 g in the mechanically thinned trees compared to the control. Using a speed of 420 rpm, mechanical thinning increased the proportion of premium fruit in Class 1 (70 mm) by 43% at 7.5 km/h and 63% at 5 km/h. However, combining mechanical and hand thinning resulted in 70% of the fruit being Class 1 fruit but at the cost of a loss in yield (55%) (Seehuber, Damerow et al. 2014). A similar system with horizontal shafts and plastic tines was on display at Fruit Focus in 2014 and is commercially available - the Flexitree from Clems Gmbh.

Figure 6. Example of the BAUM thinner in action

Further trials in Germany (Table 5) suggest both faster forward and rotational speed of 360 rpm, 5–7.5 km per hr can have a positive effect on fruit quality parameters including size (15% larger). They also showed benefits in terms of firmness (8.4 in Gala vs. 7.6 kg cm^{-2} in the un-thinned control), sweetness (124 vs. 117 g kg^{-1} sugar in the control), highest malic acid content (4 g kg^{-1} vs. 3.4 g kg^{-1} in the control) and 17% more anthocyanin (normalised anthocyanin index= 0.8 in Gala vs. 0.7 in the control). Gala also showed additionally advanced starch breakdown and ripened earlier (Solomakhin and Blanke 2010). These quality parameters require further investigation as they are likely to have influence on fruit storage ability.

Table 5. Shows the effect of a mechanical thinning device in Mondial Gala apple trees in 2008 (Solomakhin and Blanke 2010)

Mechanical thinning	ICT index	Damaged leaves per branch (%)	Damaged buds and shoots per branch	Removed flowers per cluster	Fruit set (fruits per 100 flower clusters)
Unthinned control	NA	NA	0	0	92.8
Manual thinning	NA	NA	0	0	74.3
$30 \times g$, 300 rpm, 5 km h^{-1}	9	22.3*	0.77	0.44*	85.2
$43 \times g$, 360 rpm, 5 km h^{-1}	17	23.3*	0.41	0.45*	66.7*
$43 \times g$, 360 rpm, 7.5 km h^{-1}	8	10.6*	1.13*	0.37*	77.7
$59 \times g$, 420 rpm, 5 km h^{-1}	61	42.1*	1.46*	1.00*	57.8*
$59 \times g$, 420 rpm, 7.5 km h^{-1}	35	23.7*	1.10	0.94*	62.7*
Our target	10–40	<33%	<1.3–1.5	Approx. 1.0	50–70%

* Significant difference according Dunnett-T3, $P > 0.05$; NA, not applicable.

Drum shaker thinner

In North America a drum shaker thinner was first developed from a citrus harvester and more recently a drum shaker thinner has been developed from blackberry harvesters. The USDA spiked drum shaker has been used in North America on peach trees. In trials the drum shaker thinned the peach crops successfully; however, it was reported to be not as effective as the Darwin (Miller, Schupp et al. 2011). Across the trials the drum shaker removed an average of 37% green fruit, whereas the Darwin removed up to 50% of the fruit (Miller, Schupp et al. 2011).

Figure 7. Image of the drum shaker thinner in action (Nicholson 2012)

Hand held mechanical thinners

There has been some interest in hand held mechanical thinning devises as they have the potential to be more precise by allowing growers to target the fruit that they want to remove. It is believed that they would be useful to follow up other mechanical options of thinning, such as the Darwin. The Electro'flor is a battery operated handheld thinner and is made by the French company Infaco.

The Electro'flor was tested on cherries in Penn State University trials and proved successful, although its results were not quite as good as hand thinning. Hand bud removal and hand bloom thinning resulted in the largest fruit but the handheld thinner was as good as hand fruitlet thinning (Nicholson 2012). The Electro'flor was much less labour intensive compared to the hand thinning although manipulation of the device for extended periods was reported to be physically demanding and progress slow, therefore it might possibly be unsuitable for large commercial enterprises. The Electro'flor is currently being sold throughout Europe and North America and is available in the UK.

Figure 8. Image of the 'Electro'-Flor' hand held thinner (Nicholson 2012)

Novel mechanical approaches

In Belgium at the RSF pcfruit research station novel research is ongoing in collaboration with Leuven University looking into the practicality of using powerful blasts of compressed air for flower removal. Early results show some potential in narrow fruit wall systems where air nozzles can be within 20 cm of flower clusters (Maas 2014). Links to the imaging technologies discussed in following sections may be possible in the future as the technology develops.

The use of models

A model was developed by Jones, Bound et al. (1998) Jones, Bound et al. (1998) that incorporates six major factors (chemical used, variety, rootstock, tree age, tree size, fruit size desired) and three other modifying factors (previous crop, rate of vegetative growth and pruning severity). This model was developed for use in Australia to improve the predictability of thinning and to help growers determine the optimum cropping load for their trees. The basis for the model is a mathematical matrix of optimal cropping load. Data was used from experiments carried out over the last 20 years

There have also been computer programs that have been developed to assist growers in making decisions over what concentration of chemicals to use (Dennis Jr 2000). A decision support system was developed to help growers in Colorado with apple thinning (Rogoyski and Renquist 1992). The main way in which this model helps is by determining the tree responsiveness to chemical thinning agents. It works by incorporating the user's answers to a series of questions related to the physiological status of the trees, environmental data, bearing history and the apple variety in question. The system then gives general recommendations based on the variety selected, and specific ones for that site, based on the growth stage and tree responsiveness to thinners.

More recently a model has been developed in New York State to determine the relationship between thinning and carbohydrate levels. This model is referred to as the MaluSim model (previously known as the Carbohydrate (CHO) Model). Trials were carried out between 2002 and 2008 to quantify the variability within years and to examine spray timing effects with different chemicals on mature vertical axis Royal Gala/ M9 apple trees. Daily maximum and minimum temperature and sunlight levels are used by the model to estimate whole tree carbohydrate supply and demand by the different parts of the tree. Periods of significant carbohydrate deficit, determined by the model, seem to significantly change the underlying pattern which gives rise to the variability in thinning responses seen year to year (Robinson and Lakso 2011).

A model has also been developed to predict the response of chemical thinners within 7-8 days of application, well before the final effect could be observed (Greene, Lakso et al. 2013). This model, known as the Fruitlet Growth model, involves tagging 105 spurs on seven individual trees distributed appropriately in the orchard then taking a minimum of two measurements, one 3-4 days after application and the second 7-8 days after application.

Data is then fed into the model to assess if the fruit is likely to abscise. The assumption is that if the fruit growth rate of a particular fruit over the measurement period is less than 50% of the growth rate of the fastest growing fruit on the tree during the same growth period, it will abscise, whereas if fruit growth rate exceeds 50% of the growth rate of the fastest growing fruit, it will persist (Greene, Lakso et al. 2013).

Precision crop load management

Precision crop load management (PCLM) is a concept put forth by a team of researchers at Cornell University in New York State whereby a more prescribed system is recommended to guide thinning decisions. PCLM includes precision pruning, precision chemical thinning and precision hand thinning (Robinson, Hoying et al. 2014). PCLM addresses the issue that crop load management is the most important factor in annual profitability of an apple orchard. The precision chemical thinning element relies on the use of the two models discussed above; the MaluSim model and the Fruitlet Growth model. The concept involves a multi-step approach to manage crop load whereby the rate of chemical thinner is adjusted +/- 30% in response to the results of MaluSim and all subsequent sprays are guided by the Fruitlet Growth model (Figure 9).

Two years of field scale trials and extension work have taken place and grower response and thinning results have been very promising (Mario Miranda Sazo, personal communication, 31 October 2014). Hundreds of growers, researchers and farm managers have attended meetings and training sessions over the past two years to learn about PCLM and over 50 growers have now implemented PCLM through more aggressive pruning and a precision thinning programme using the results of the models, with this number expected to rise again in the coming season (Mario Miranda Sazo, personal communication, 31 October 2014).

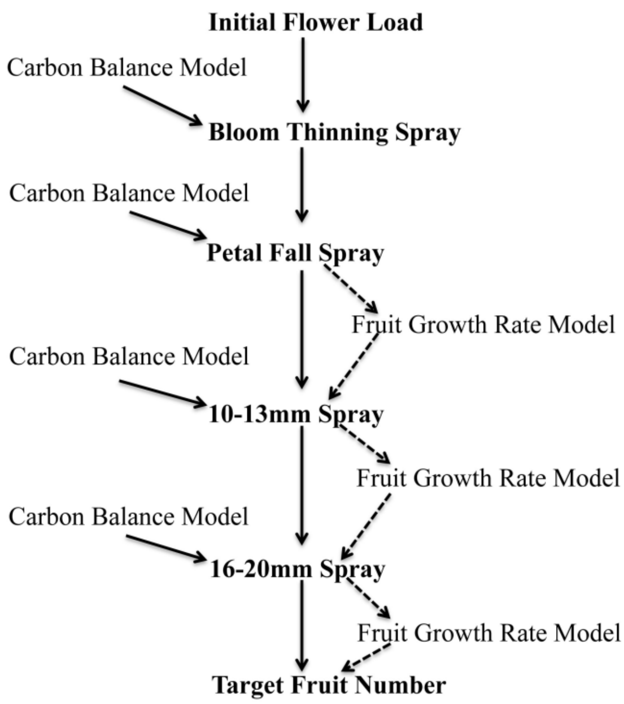

Figure 9. Decision making tree according to Precision Crop Load Management (Robinson, Hoying et al. 2014).

Currently, labour requirement is a limiting factor of PCLM because the process involves marking and measuring 15 flower clusters on five trees within an orchard. Approximately 6 man hours (3 hours x 2 workers) are required for the initial measurement followed by 4 man hours (2 hours x 2 people) for each subsequent measurement. This however, has been justified in New York as growers are seeing as much as $5-10,000 USD/acre increase in crop value (Mario Miranda Sazo, personal communication, 31 October 2014).

Benefits of models to UK growers

The use of models increases the science behind decisions to thin and in many cases there may be potential benefits to UK growers if these models could be used here. MaluSim, for example, uses weather data to determine how effective a chemical thinner will be based on the carbohydrate levels at that time. ADAMA, who are developing metamitron as a thinner, are very interested in utilising this model to optimise application timing. In the UK, where conditions are often not ideal for chemical thinners, the use of this model may reduce the unnecessary application of chemical treatments which will have little or no effect at that time. The Fruitlet Growth model may also be useful to UK growers. Understanding which fruit have been affected by a chemical treatment, and therefore will fall in due course, allows growers to make the decision to re-spray earlier than would otherwise be possible or provide an early warning of how much hand thinning will be required - this would be particularly useful for BA as thinning effects can take time to see by eye. The MaluSim model has been identified by EUFRIN as a valuable tool to aid optimal use of photosynthesis inhibitors such as metamitron (Maas 2014).

Shading

It is believed that shading fruitlets for short periods of time causes a modification in the carbohydrate balance, worsening the supply to young fruit during a period of intense growth (Byers, Lyons et al. 1985, Byers, Barden et al. 1990, Byers, Barden et al. 1990, Byers, Carbaugh et al. 1991, Grappadelli, Lakso et al. 1994). This modification increases the competition between different sinks and leads to the abscission of weaker fruit. The period from bud break to approximately 30 days after full bloom is when the tree is most susceptible to fruit loss through artificial shading due to a net loss in carbon reserves (Byers, Carbaugh et al. 1991, Byers 2003). The same mechanism applies when using chemical photosystem inhibitors e.g. metamitron (Byers, Lyons et al. 1985). In addition to fruit drop, shading has been shown to increase fruit size and quality (Zibordi, Domingos et al. 2009, Basak 2011). In some cases, shading has led to over-thinning and reduced yields (Lakso, Robinson et al. 1989).

The level of fruit drop achieved through artificial shading depends on the apple variety (Kockerols, Widmer et al. 2008), length of time shade is applied, growth stage at the start of the shading period and the degree of shading applied (Byers, Lyons et al. 1985, McArtney, White et al. 2004, Kockerols, Widmer et al. 2008, Zibordi, Domingos et al. 2009, Basak 2011). Suggestions of optimal periods for shading vary by author, ranging from three days beginning 19-33 days after full bloom for the apple variety Golden Delicious (Kockerols, Widmer et al. 2008) to ten days beginning from when fruitlets measure 6 mm for Gala Must apples (Basak 2011).

Although shading does show some promising results there are risks involved. Specifically, a better understanding of the specific timing required for shade application and a prescribed method to estimate this time would be required. Additionally, current methods of applying shading to a crop are too costly and time-consuming for mass adoption (Kockerols, Widmer et al. 2008) so a cost-effective method would need to be developed. Covering systems e.g. for cherries are becoming commonplace and practical, with climate change and the potential for more extreme weather UK tree fruit growers may start to follow growers on the continent and invest in hail netting. A shading system could utilise this system and be a valuable non chemical non harmful thinning tool. Shading for short periods may also improve efficacy of chemical thinners such as BA.

Imaging technologies

Through the course of this review some interesting imaging technologies have been identified in new research projects in the UK being carried out by Worldwide Fruit in association with East Malling Research (EMR), Copella Farms and Fruition PO. These include the use of LiDAR (Light Detection and Ranging), which is a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light. In an orchard this can be used to plot the location and produce a spectral image of every tree in that orchard, producing a measure of tree height and/or tree row volume. Tree structure has been shown to be a key factor influencing the productivity of tree fruit, determining light penetration and therefore bud development and optimal fruit set (Walklate 2014). In the current work the data being collected is being correlated to yield, fruit size and quality to calculate optimum tree row volume. This will be used to inform pruning operations resulting in optimal levels of wood in the tree to give the canopy required (Tony Harding, Worldwide Fruit personal communication, 12 September 2014).

The other technology being developed by the Technology Research Centre is a quad bike mounted camera system (either one or two required depending on the height of the orchard) known as Omnia Fruit Vision. These cameras do not capture an image as such but rather the GPS coordinates of apples on the trees which can be plotted onto Google Earth to give an up to 95% accurate apple count of every tree in an orchard and indicate where fruit is growing on the tree to give an idea of quantity. The current prototype (Mark 1) can count apples which are golf ball size or larger and is being trialled from June drop up to harvest to inform summer hand thinning, summer pruning and yield estimations. Mark 2, which is likely to be ready in 2015, should be able to estimate apple size and give a size distribution across the orchard from 6 weeks after June drop. Mark 3 should be able to pick up colour and blemishes to assess quality (Technology Research Centre personal communication, Fruit Focus, 2014). It is unlikely the Omnia Fruit Vision system will be able to count apples smaller than golf ball size in the near future, due to difficulties with leaves shielding fruitlets and reflectance, so use of this technology for informing fruitlet thinning may not be possible but accurate fruit counts will show success of earlier thinning strategies (chemical or mechanical) and inform later size and quality thinning activities. As technology advances there is the potential to link it to novel strategies such as the air thinning system described previously being investigated at the RSF pcfruit research station in Belgium.

Imaging technologies offer another approach to whole tree management which could support thinning practices, the theory being that through better understanding of tree architecture or by more accurately being able to count apples one can get close to the optimal tree architecture during winter pruning to ensure enough but not too much vigour and reduce or limit the necessity of extensive thinning activities (Tony Harding, Worldwide Fruit personal communication, 12 September 2014). However, being able to translate and interpret the data collected is imperative to being able to use it effectively.

Conclusions

- This review has demonstrated that the UK's approaches to fruit thinning, in comparison with global practices, are very similar. We may have fewer chemicals at our disposal than some nations but very similar challenges are experienced globally.
- The biochemical processes involved in fruit set and fruit drop are complex and are controlled by a wide variety of parameters. Understanding these and how thinning approaches are acting upon them is critical for optimal reduction in fruit number.
- Learning to trust mechanical thinning and to optimise its use through trials work and investigating more about whether there are any long term effects of its use, is likely to prove it to be a cost effective option for thinning in our cooler climate.
- Gaining approval for metamitron in the UK is an exciting prospect as it appears to be a less temperature dependant fruitlet thinner than those currently approved.
- Getting the most out of chemicals already available through the use of combinations of chemicals, adjuvants and utilising models such as the MaluSim and Fruitlet Growth models will optimise and inform chemical fruit thinning timing and rates.
- The majority of the evidence from literature suggests that the size of the crop load, rather than the way that crop load was achieved, will have a greater effect on crop quality and storability. However the limited number of experiments which recorded fruit quality parameters such as firmness and Brix demonstrate some very mixed conclusions with both positive and negative effects on fruit quality from both mechanical and chemical thinning strategies. With a desire in the UK to be able to store apples (particularly Gala) for longer, understanding these effects would be very valuable.
- A major gap in the research is the long term health effects that different thinning techniques have on the trees. Further work will need to be done in this area comparing methods to ensure that we are not compromising future crops by thinning in certain ways.
- Integrating thinning methods to optimise marketable fruit yield is the next step

This review has further demonstrated the potential of mechanical thinning, identified some new chemistry and also highlighted some models that have been developed in the USA to help growers with some of the uncertainty of the chemical thinning, both in terms of when to thin, what chemical concentrations to use and how effective thinning may have been according to the environmental conditions.

- Development of these types of models for UK systems and conditions would be valuable in targeting the timing and likely impacts on productivity of using selected thinning techniques.
- Their use alongside imaging technologies to inform optimal winter pruning strategies along with integration with mechanical techniques would take some of the uncertainty out of the process of thinning and hopefully improve efficacy and cost effectiveness.

Recommendations - opportunities for future studies

Through the course of this review it is clear there is no silver bullet to revolutionise how tree fruit is thinned. Current methods have their limitations and there are gaps in our knowledge and understanding of how current thinning methods work and what effects these methods could be having on fruit quality and tree health. We therefore recommend the following ideas for future studies to try to address the uncertainties associated with thinning and support the UK industry to thin more effectively and consistently:

- Carry out a targeted comparison of growing practices to identify those having greatest impact on fruit storage potential of Gala and Braeburn – a review of commercial practice, identifying comparable plantations around the country utilising different thinning strategies/growing practices and recording all aspects of crop husbandry. This could link directly to and expand upon the recommendation made in TF 222 re 'confirming the relationship between DMC and ex store quality'. Fruit from these carefully selected orchards would be followed through to harvest to record yield and quality attributes, taking sub samples to assess fruit quality attributes out of store. The data set produced could be extensively interrogated to identify which practices improve aspects of quality.
- Trials comparison of thinning effects on fruit storage ability – based on the results of the survey or as a standalone experiment we recommend a fully replicated commercial trial of thinning practices comparing the various methods currently available or likely to become available in the next two years including:
    - mechanical,
    - chemical and

- combined approaches

all compared with a hand thinned and no thinning control. The trial could be run along the lines of TF 197 with records made for time taken to thin using the various methods, efficacy of thinning approaches, yield and quality attributes post-harvest to produce a detailed cost benefit analysis. Additionally a further stage could look at thinning effects on fruit mineral content and storability by assessing stored fruit remove periodically from store, giving firm evidence on the advantageous/ disadvantageous effects of available thinning methods on fruit storage quality.

- Physiological study of Gala looking at components of yield and storability – detailed information is well publicised for Cox and increasingly club varieties such as Jazz on the precise management requirements - crop nutrition, planting density, crop loads etc. Although Gala is being widely grown successfully without specific physiological research on management systems (i.e. nutrition, optimal crop loads) we may be missing opportunities to improve Gala quality and potential storability.
- Thinning model development for the UK – develop Precision Crop Load Management tools with the use of the MaluSim and Fruitlet Growth models. These models are showing very promising results and suggest a more scientific method for optimising chemical fruit thinning. It is recommended that UK researchers work with the American researchers to validate the US work for UK conditions and chemistry.
- As labour requirements are a concern for Precision Crop Load Management, developing an improved method for recording fruitlet growth rate would be very beneficial and could perhaps link in with the Omnia Fruit Vision technology
- UK representative on the EUFRIN group – this group is at the forefront of thinning research in Europe although we did manage to talk to representatives during this review their research is not widely accessible. To keep up to date with the newest chemistry, theories on adjuvants and tank mixes as well as more novel approaches, the UK needs a representative on this group. Membership requires commitment to carry out self-funded trials to match the group's activities so funding strategy would have to be agreed. Details of commitments have been requested and will be provided to HDC.
- Experimental work to identify optimal use of combinations of chemical thinners with and without novel products or adjuvants under UK conditions. To include metamitron, BA, ATS and potential NAA if approval can be gained along with

products such as lime sulphur and potassium bicarbonate. Extensive research has been carried out within the EUFRIN group for continental Europe however it may be prudent to carry out some UK specific trials work on combinations and mixtures under temperate maritime conditions.

- Review longer term effects of mechanical thinning techniques on tree health – identify orchards within Europe and New Zealand where this method has been used for sequential years to assess for reductions in return bloom, or effects on diseases such as Canker. Potential study tour to gather information
- Experimental comparison of mechanical thinning equipment - compare the Darwin system with the BAUM/Bonner and others available on the market for different growing systems
- Investigate the potential of shading as a thinning strategy in the UK – impressive results are shown in the literature with this method. Covering systems e.g. for cherries are becoming commonplace and practical, with climate change and the potential for more extreme weather UK tree fruit growers may start to follow growers on the continent and invest in hail netting. A shading system could utilise this system and be a valuable non chemical non harmful thinning tool. Shading for short periods may also improve efficacy of chemical thinners such as BA
- Investigate spray application techniques to see if chemical thinning of products such as ATS which require good contact with the centres of flowers can be improved through, changes in volume or nozzle technology.
- Update the HDC Apple Best Practice guide sections on thinning based on the findings in this review. Update the guide to a smart phone friendly format. Provide timely updates with links to best practice advice at key thinning milestones through the season.

Cost comparison of novel and combined of approaches

The final objective of this project was to produce a cost benefit analysis of thinning approaches. A detailed cost benefit analysis was produced in TF 197 from specific directly comparable trials data. It is not possible to do the benefit part of this sort of analysis without information of efficacy of thinning achieved by each method so a simple cost comparison has been produced with the assistance of growers and consultants.

Full details of each programme are written below. Programmes are based on a five year old Gala orchard planted at 3m x 0.8m.

Programme one involves a mixture of chemical and hand thinning approaches. The chemical used is ATS and assumes three applications of ATS would be applied, which would be made to cover the whole tree. Two lots of hand thinning would also be included in this typical programme. The first hand thinning operation would take place from early June at the 12/15mm stage and would involve thinning the clusters down to singles or doubles. It has been assumed that this first round of hand thinning would take 125 hours per hectare. The second round of hand thinning is used to quality thin, removing marked fruitlets and poor shaped fruits, with the aim of achieving 1.2 fruit per cm planted distance. It has been estimated that this quality hand thin would take 50 hours per hectare.

Programme two is based on the use of mechanical and hand thinning only. This can be a viable option for thinning apple trees in some years, however it is very much weather dependent, especially the weather conditions after blossom thinning. This programme would include one pass through with the Darwin which would then be followed up with one/two rounds of hand thinning. For the purpose of this costing exercise one round of hand thinning has been assumed but it has been estimated that this round of hand thinning would take 150 hours per hectare.

Programme three is purely a hand thinning programme. For a hand thinning only programme there would still only be two rounds of hand thinning but each round would take longer than the hand thinning parts of the previous programmes mentioned. For this programme we have estimated that there would be a total of 250 hours of hand thinning.

The fourth programme involves ATS, BA and a hand thin. ATS would be applied once at blossom and then one application of BA would be used to thin fruitlets. A small quality hand thin would also be included in this programme which has been estimated to take 50 hours.

Table 6 below shows estimates for the total cost of each of programme. Costs are based on £ per hectare. **Table 6** splits costs into costs per hour of a person’s time, cost of chemical per hectare, number of times the application or operation is required and the number of people hours required per hectare. It must be noted that the direct cost of the Darwin thinner has not been included in these costs, the price of the Darwin thinner is around £9,000. There is the option to rent equipment, however this not always practical due to difficulties in predicting when the correct thinning conditions are going to occur and therefore when the equipment will be required.

Table 6: Cost analysis for four different apple thinning programmes. Costs are shown in £ /ha.

Method	**Cost per hour (£/hr)**	**Cost of chemical per ha (£/ha)**	**Frequency**	**Number of people-hours required to thin 1 ha**	**Total cost per ha**
1 - Use of chemical blossom thinner followed by hand thinning as required	£8.50	NA	2	175 (125 hrs for first lot of hand thinning and 50 hrs for second lot)	**£1657**
	£12.50	£50	3	0.5	
2 - Use of a mechanical blossom thinner followed by hand thinning as required	£12.50	NA	1	1.25	**£1291**
	£8.50	NA	1	150	
3 - Purely hand thinned	£8.50	NA	2	250 (assuming each hand thin took 125 hrs)	**£2125**
4 - Combined chemical blossom and fruitlet thinner	£12.50	£50	1	0.5	**£689**
	£12.50	£202 (assuming a price of £27/L and assuming applied at a rate of 7.5L/ha	1	0.5	
	£8.50	NA	1	50	

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Appendix 1: Persons contacted through the course of the review

Name	**Position**	**Location**
Gerhard Baab	Leader at a Research Centre in Horticulture near Bonn	Germany, with strong links with Belgium and the Netherlands
Nigel Kitney	Apple grower and Agronomist at Hutchinson's	Hereford, UK
Frank Maas	Fruit tree Physiologist and Pomologist at Bioforsk	Netherlands
Cor van Oorschot	Farm Manager, Wisbech Contract farming	Currently based in the UK, Fruit growing experience in Netherlands, Germany and UK
Jan Peeters	Co-owner, Fruitconsult	Based in Holland but covers various European countries
John Portass	Managing director, Wisbech Contract Farming	Wisbech, UK
James Smith	Managing Director, Loddington Farm	Kent, UK
Brian Tompsett	Consultant, Apple Growing Solutions	Kent, UK
Tony Harding	Technical director, World Wide Fruit	Kent, UK
Leslie Huffman	Apple Specialist, Ontario Ministry of Agriculture, Food and Rural Affairs	Ontario, Canada

Michael Blanke	Professor, University of Bonn, INRES Horticultural Science	Bonn, Germany
Mario Miranda Sazo	Extension Associate, Cornell Cooperative Extension, College of Agriculture and Life Science	New York, USA
Paul Fogg	Technical Manager, ADAMA UK (formally MAUK)	Berkshire, UK
Nick Seymour	Director, NP Seymour Ltd.	Kent, UK