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Project leader:	Mr C T Biddlecombe Farm Advisory Services Team Ltd. Experimental Farm North Street Sheldwich Faversham Kent ME13 0LN
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Key workers:	Mr C T Biddlecombe Dr C J Atkinson
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CONTENTS

Headline

- Orchard pruning costs can be reduced by ‘mechanical’ dormant season pruning but follow up hand pruning would be needed for areas not cut by the equipment.

- Flower thinning can be effectively and environmentally sensitively achieved using high pressure water jets but follow up hand thinning would be needed for areas not reached by the equipment.

Background and expected deliverables

Economic production of orchard fruit is dominated by the costs involved in labour intensive activities, such as pruning in the dormant season and thinning of flowers and fruitlets in the spring. There is also an important associated issue of the continual UK decline in the availability of skilled staff to carry out these manual orchard operations.

This project builds on the APRC desktop study (formerly SP 136 and now TF 136), which recommended that research be focused on mechanical methods of tree pruning, and of flower and fruitlet thinning.

This research aims to deliver validation of potential methods to reduce:

- The costs associated with pruning and thinning of flowers and fruitlets
- The demand for skilled labour to undertake these operations
- The cost and environmental impact of chemical applications to thin flowers and fruitlets

Summary of the project and main conclusions

Pruning during the dormant season caused a reduction in flower bud number due to removal of a portion of the tree containing flower buds. Hand pruning resulted in a greater reduction in flower buds than mechanical pruning as hand pruning removed wood from all around the tree whereas mechanical pruning only removed wood parallel to the grass strip, leaving wood between trees in a row unpruned.

The effect of pruning during the dormant season on fruit number was to reduce the number of fruit on pruned trees compared to unpruned trees, a trend that follows flower bud number. However, these differences were not statistically significantly different. Although the hand pruned trees had a lower number of flowers there was no reduction in the number of fruit compared to mechanically pruned trees.

Figure 1. The 'A' frame ('simulated mechanical pruning') being used to determine which branches to manual prune at what point, to simulate a mechanical cutter bar operating in the orchard at the same angle as the 'A' frame. 13 year old Queen Cox trees are being treated at EMR.

Generally there was no difference in fruit size and weight, although in unpruned Queen Cox with no Cultar treatment fewer fruit in the 66 to 70mm size class were produced. This was however, not the case when Cultar was applied, suggesting that Cultar had a beneficial effect on fruit size in this case.

It must be remembered that the results for flower bud number, fruit set and yield are for trees that have only had two years treatment. That is to say that the potential for flower buds is dependent on the previous year's growth when all of the trees were pruned conventionally. The results in the following year that show a large increase in Cox flower bud number, with few exceptions, has little to do with treatment. For Bramley, there were no seasonal changes in flower number per tree, but a big increase in fruit set which impacted on enhancing the proportion of fruit in the smallest size class.

It can, however, be concluded for both cultivar and years that there was no obvious negative impact on fruit yield (number or weight), caused by adopting simulated 'mechanical' pruning. This was particularly true on comparing the dormant pruned treatments with the hand pruned trees. The high yields with respect to non-pruned trees have to be off-set by the poorer quality fruit (increased proportion in the smallest size class). These results suggest that there will be a considerable economic benefit and growers should be encouraged to try mechanical methods, rather than labour intensive hand pruning in the dormant season.

Figure 2. A high pressure commercial washer being used to manually delivering a blast of water to Queen Cox trees to remove blossoms at flowering time.

High pressure water jets have been shown to be an effective method of flower thinning in both Queen Cox and Bramley's Seedling. The effectiveness of this technique is however dependant on timing, distance of the water jet nozzle from the buds and pulsed or sustained application. High pressure water jets were shown to remove between 0 and 58% of the buds on Bramley's Seedling and 6 to 54% of the buds on Queen Cox trees.

However, an effective method of commercial application still needs to be determined. This is because at present the technique would not be effective on buds located towards the centre of the row as these buds would be too far from the spray nozzles for effective thinning. This would increase crop loading towards the centre of the tree and cause a decrease in colour development and crop quality due to shading. Therefore further research is needed to develop and engineer a commercial method of applying this technique effectively throughout the canopy.

The conclusions are:

- In theory, orchard pruning costs can be reduced by 'mechanical' dormant season pruning
- The pruning method used did not rely on skilled pruning decisions

- The mechanical method was used to convert an existing conventionally pruned orchard; there may be benefits in adopting 'mechanical' pruning approaches earlier in the tree/orchard's life
- Simulating mechanical pruning in Queen Cox and Bramley's Seedling orchards was effectively and easily achieved
- With few exceptions, for Queen Cox and Bramley's Seedling, fruit yields over the two years were not negatively influenced by simulated mechanical, particularly with respect to the hand pruned trees.
- Not pruning increased flower and fruit number but again with both varieties did have a negative impact on fruit size.
- The influences of pruning and PGR application on shoot growth, after two years, and only one set of measurements were minimal
- Despite no negative impacts of mechanical pruning on the cropping of either Queen Cox or Bramley's Seedling these experiments still have to be considered as short-term
- Further work needs to establish the impact of these types of changes over longer periods of time
- Flower thinning can be effectively and environmentally sensitively achieved using high pressure water jets; this area warrants further developmental study

Financial benefits

It is estimated that the industry spends £3-4 million per year on pruning, £2-3 million on thinning and a further £6-10 million on crop harvesting. There is a serious skill shortage developing in the industry for these basic manual operations. Both the mechanical pruning and thinning methods explored in this trial show promise for reducing these cost and reliance on skilled or semi-skilled labour.

Action points for growers

- Consider mechanical pruning in suitable orchards but hand prune the parts of the trees not cut by the equipment.
- Consider the use of high pressure water jets for thinning but follow up with hand thinning.

Science Section

Introduction

It is estimated that the industry spends £3-4 million per year on pruning, £2-3 million on thinning and a further £6-10 million on crop harvesting. There is a serious skill shortage developing in the industry for these basic manual operations.

The Top Fruit Husbandry Committee within the APRC had for some time been developing an interest in examining ways to reduce labour costs associated with manual operations within fruit orchards. To achieve this, research proposals were submitted in November 2000 for APRC support. The submitted projects focussed on ways of reducing the labour requirement in apple and pear growing. These proposals were welcomed and a subcommittee was formed to progress and develop the ideas further. As part of the APRC interest in labour saving, a desktop study was commissioned to report on published work detailing key areas where labour reductions might be possible. The report (SP 136 now TF 136) written by Dr A.D. Webster (Independent consultant) and Dr N.D. Tillet (Bio-Engineering Division, Silsoe) was completed in April 2002.

The report covered the following:

- Pruning and training
- Flower or fruitlet thinning
- Harvesting

Scientific research and commercial development undertaken throughout the world during the last 10 years was surveyed and the following alternative and future orchard management strategies were considered in the report:

Pruning	-	Use of cultivars with compact or spur type habit
	-	Use of dwarfing rootstocks
	-	Use of chemical growth retardants
	-	Use of root pruning or restriction
	-	Robotics
	-	Mechanisation
	-	Columnar type trees
Thinning	-	Mechanical thinning of fruitlets and flowers
Harvesting	-	Mechanical harvesting
	-	Robotic harvesting

The APRC subcommittee considered the SP 136 (now TF 136) report and prepared a concept note, which built on its key findings, for submission to the HDC when they took over the duties of the APRC.

Several growers in the UK are already experimenting with mechanical pruning in an attempt to reduce their labour costs. The success of these techniques is limited due to the varied and unpredictable amount of tree regrowth that occurs. Much of this variability is likely to be due to the extent of pruning treatments and the times at which they are applied. However, this level of detail is not currently known. Also, the long term cropping effects due to poor return fruit bud (carry-over) and reduced fruit set are often not fully monitored or scientifically quantified.

This project develops the key recommendations made within the review TF 136 and outlines a 'proof of concept' process regarding the potential to develop mechanical methods to prune trees and to thin flowers and fruitlets. This 'proof of concept' process will be tested in established maturing orchards that currently require extensive manual pruning. An added benefit deriving from this project would be a reduction in the need and cost of chemical applications to thin flowers and fruit. This would also reduce the environmental impact of these chemical treatments.

The current project does not attempt to provide the industry with a 'best practice' solution. To achieve best practice further more detailed & focussed research work is envisaged, particularly that associated with the extent of pruning and time of treatment.

Materials and Methods

Plant material

Queen Cox planting at EMR

An experimental trial was set up at East Malling Research (EMR) using Queen Cox trees spaced at 4m between rows and 2m between trees. These trees were all within single cultivar rows (same row) over two experimental plantings (CW 120 and CW 121) running north-south. The trees were planted in 1991 and were 13 years old when the first experimental treatments were applied. The orchards contained single rows of 'Royal Gala' and 'Fiesta' which acted as pollinators (see Appendix IV for plot plan and location of treatments).

Bramley's Seedling planting at Figgis' Farm

The Bramley orchard (Brick Close) is located at Wey Street Farm, Hernhill, Faversham, Kent. The orchard was planted during the winter of 1989-90 and has a north-south orientation on a north facing slope. It is planted as a single row layout with trees on M9 rootstock. The soil is a sandy clay loam with a pH of 6.7 (see Appendix V for plot plan and location of treatments).

Experimental design

From the Queen Cox orchard described above 77 trees were selected from a single row running through the plantings, and from the Bramley's Seedling orchard 77 trees were selected from two adjacent rows. For both plantings nine treatments were applied as follows:

Table 1. Treatments applied to Queen Cox plantings at EMR and Bramley's Seedling at Herne Hill.

Treatments				
Treatment Number #	Dormant pruning application	Dormant season application of 'Cultar' (PGR)	Petal fall pruning application	Petal fall application of 'Cultar' (PGR)
1	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	No
3	Yes	Yes	No	No
4	Yes	No	Yes	Yes
5	Yes	No	Yes	No
6	Yes	No	No	No
7	No	No	No	No
8	No	Yes	No	No
9	Hand	No	No	No

The experiment contained seven blocks of trees with each block containing one of the nine treatment replicates. Each of the seven blocks was separated by at least one guard tree. Blocks were arranged so that they were within one original orchard. Each treatment was randomly assigned to its position (single tree) within any one block, so the order of treatments along the row was different for every individual block. This yielded seven single tree treatment replications. All trees were individually labelled and tagged (colour coded) prior to treatment application. The same experimental design was used in 2004 and 2005. The same basic experimental design was also used for the Bramley's Seedling experiments as described below (see Appendix V for plot plan, location of treatments and codes).

Treatment application

Mechanical pruning

As treatments were to be applied to single trees, mechanical pruning was simulated manually. This was achieved by the use of a transportable 'A' frame pro-forma constructed to enable the same tree shape to be applied to each tree. The 'A' frame determined where a branch extended beyond the desired new tree shape and was therefore removed by manual pruning (see Figure 1). The same pruning procedure was used in both 2004 and 2005. All pruning and PGR applications were applied initially in the dormant season starting on 18 March 2004 and on 21 March in 2005 fro the Queen Cox orchard. While the Bramley's Seedlings treatments started on 24 March in 2004 and on 23 March in 2005.

Figure 1. The 'A' frame ('simulated mechanical pruning') being used to determine which branches to manual prune at what point, to simulate a mechanical cutter bar operating in the orchard at the same angle as the 'A' frame. 13 year old Queen Cox trees are being treated at EMR.

Flower thinning

Flower thinning was carried out using a commercial spray washer to deliver high pressure water (6 Bar) directed at flower clusters manually. Different treatments were carried out to determine effectiveness of the spray at a range of distances from the clusters (5, 10, and 15 cm). These treatments were applied as short bursts of two seconds duration and in addition to these treatments a sustained continuous jet of water was applied along the length of the branch at a distance of 10cm. As this was carried out manually, only simulating likely tractor mounted mechanical thinning, the nozzle was positioned and moved parallel with the treated length of branch during the pressure sprays. For each treatment flowers within flower clusters were counted along one or two sections of a single branch.

The flower thinning treatments were applied on three dates to determine the effectiveness of these treatments when applied at different times. The treatment dates were 5, 15 and 27 May 2004.

Figure 2. **A high pressure commercial washer being used to manually delivering a blast of water to Queen Cox trees to remove blossoms at flowering time.**

Shoot growth measurements

In the dormant season of 2004-05 estimations of shoot growth were made for both the Queen Cox and Bramley's Seedling orchards, with reference to the production of new wood, i.e. only shoot growth in 2004 was recorded. Due to the large amount of existing shoots (prior to treatment application in 2004), particularly for the Bramley's Seedling orchard experiment (Figgis' Farm), not all shoots were measured. For both Queen Cox and Bramley, the total number of shoots was determined directly from whole tree counts. Twenty five shoots per tree was designated as an appropriate number to determine mean shoot length per tree. Once total shoot number per tree was determined it was possible to establish the interval for selection of shoots to be measured, i.e. 200 shoots per tree requires measuring around one in eight shoots. Mean shoot length multiplied by the total number of shoots was used to determine total shoot growth per tree.

Experimental design and statistical analysis

The experimental design for both the Queen Cox and Bramley's Seedlings plantings were developed in conjunction with EMR statistical consultant, Dr. Gillian Arnold. The usual rigors of planning and design randomised experiments were not entirely possible here because the work involved applying treatments to existing orchard designs. However, despite this, the most appropriate design and use of experimental treatment blockings were carried out to ensure environmental and between tree variability did not confound the analyses. The analyses presented in the main body of this report also reflect the analyses considered most appropriate taking the above considerations into account. The analyses have also been approved by Dr. Gillian Arnold.

Results

Queen Cox planting at EMR

Effects of pruning on flower number in 2004

Firstly it is apparent, but not unexpected, that dormant season pruning reduced flower number considerably (Table 2). The impact, again perhaps not unexpectedly, was greatest for flowers in axillary positions where flower number was highest for unpruned trees in treatments 7 and 8. The dormant season pruning had generally less influence on spur flowers. Despite this significant difference in axillary flower, the unpruned treatment 8 did not have the highest total number of flowers, because axillary flowers proportionally contribute little to the total flower number per tree.

Mean total flower number per treatment varied from 222 (treatment 5) to 387 (treatment 7), with hand pruned trees (treatment 9) having 226 (Table 2). These results are likely to also reflect tree variation and in general it can be concluded that treatment differences were small, only on some occasions being statistically significant from manually hand pruned trees (treatment 9).

Table 2. The effects of pruning during the dormant season (March) and concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean flower position (terminal, axillary and spur) per Queen Cox tree, measured over 20-23 April 2004.

Treatment			Number of flower clusters per tree			
#	Dormant prune	Dormant PGR*	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	8	7	256	**270**
2	Yes	Yes	5	3	283	**291**
3	Yes	Yes	12	16	305	**333**
4	Yes	No	16	7	345	**368**
5	Yes	No	7	3	213	**222**
6	Yes	No	5	3	229	**237**
7	No	No	18	34	335	**387**
8	No	Yes	20	25	260	**305**
9	Hand	No	10	16	201	**226**
Treatment mean			*11*	*10*	*270*	*293*
Significance level			**	**	**	**
SED (df=48)			*4.3*	*10.3*	*53.8*	*61*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Effects of pruning on flower number in 2005
Total number of flower per tree, irrespective of treatment, was at least two-fold greater than those recorded in 2004 (Table 3). Statistical variation was particularly large and this makes interpreting treatment differences difficult. There were however few obvious treatment trends over the two seasons. One exception was treatment 9 (hand pruned no PGR), which had the fewest flowers in both years. It was also true and not unexpected that the no dormant season pruned treatments (treatments 7 and 8) were ranked in the top 4 treatments in both years, with respect to flower number per tree. The difference between the no dormant season pruning treatments (7 and 8, i.e. 750 and 1173 flowers) relative to the hand pruning treatment (9, i.e. 456 flowers) in 2005 has become larger.

The general overall distribution of flowers to terminal, axillary and spur positions was similar to that in 2004 (Table 2). In 2005, 94% of the flowers were classified as spurs with 4% in terminal positions and 2% as axillaries (Table 3), compared to 92%, 3.4% and 3.7% for the same flower types respectively in 2004.

Table 3. The effects of pruning during the dormant season (March) and concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean flower position (terminal, axillary and spur) per Queen Cox tree, measured on 11-12 May 2005.

Treatment			Number of flower clusters per tree			
#	Dormant prune	Dormant PGR	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	8	13	640	**661**
2	Yes	Yes	9	18	540	**567**
3	Yes	Yes	14	26	591	**631**
4	Yes	No	19	28	603	**649**
5	Yes	No	24	43	787	**854**
6	Yes	No	21	43	624	**689**
7	No	No	13	24	712	**750**
8	No	Yes	22	47	1103	**1173**
9	Hand	No	7.6	24	424	**456**
Treatment mean			*15*	*30*	*669*	*714*
Significance level			*n.s*	*n.s*	***	***
SED (df=47)			*9.1*	*21.12*	*143.2*	*164.2*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Effects of pruning on fruit number in 2004
Fruit set (number) measured after June drop varied very little with respect to fruit in either terminal or axillary positions (Table 4). Again, as with flower number, fruit number was greatest in spur positions, varying from 261 (treatment 1) to 382 (treatment 7). Total fruit number per treatment varied

from 266 (treatments 1 & 5) to 401 (treatment 7). However, despite this variation in fruit number there was no statistically significantly difference detected (Table 3). Differences were evident within the dormant season pruned trees, but only with respect to the reduced fruit number apparent with treatments 1 and 5, but again these differences were not statistically significant. Despite the lower flower number apparent with hand pruned trees (Table 2) this did not yield a lower fruit number when compared to the pruned trees (Table 4).

Table 4. The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean fruit number per flower position (terminal, axillary and spur) per Queen Cox tree, measured over 10-16 June 2004.

Treatment					Number of fruit per tree			
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	Yes	Yes	3	1	261	**266**
2	Yes	Yes	Yes	No	1	3	291	**296**
3	Yes	Yes	No	No	6	6	365	**377**
4	Yes	No	Yes	Yes	5	7	363	**375**
5	Yes	No	Yes	No	3	2	262	**266**
6	Yes	No	No	No	1	4	302	**307**
7	No	No	No	No	5	14	382	**401**
8	No	Yes	No	No	7	6	290	**303**
9	Hand	No	No	No	8	9	312	**329**
Treatment mean					*4*	*6*	*314*	*324*
Significance level					*ns*	*ns*	*ns*	*ns*
SED (df=48)					*2.6*	*5.6*	*52.3*	*55.9*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Effects of pruning on fruit number in 2005

Despite the increase in mean treatment total number of flower per tree, from 293 in 2004 to 714 in 2005, fruit number after June drop was lower in 2005 compared to 2004. Mean treatment total fruit number after June drop was 324 in 2004 (a treatment range of 266 to 401) and only 233 in 2005 (a treatment range of 170 to 291) a fall of 28%. There were similarities, however, with the treatments, not involving dormant season pruning, having the largest number of fruit, apart from treatment 4. In 2005 the hand pruning treatment had the fewest fruit.

As with 2004, the predominant source of fruit arose from spur positions, irrespective of treatment, but the proportional distribution did change with year. In 2004 spurs flowers accounted for 97%, while axillaries were around 2% and terminals only 1%. In 2005 the proportion from spur flowers fell to

92%, while the axillaries remained around 2%, the terminals increased to 6%. The increase in terminal does not seem to be linked to a treatment, as might be expected if shoot tips are not being removed by a lack of pruning. As might be expected there is the potential for a large volume of fruit to be obtained from spur positions (Cox fruit are mainly borne on spurs). The importance of spur is even more apparent, and can clearly be seen during the dormant season in Figure 11 (Appendix I), in the no dormant season pruned trees. Both treatments 7 and 8 had the highest number of flowers despite the lack of statistical treatment differences.

Table 5. The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean fruit number per flower position (terminal, axillary and spur) per Queen Cox tree, measured over 10-16 of June 2005.

Treatment					Number of fruit per tree			
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	Yes	Yes	10	4	195	**209**
2	Yes	Yes	Yes	No	14	2	221	**237**
3	Yes	Yes	No	No	9	1	228	**238**
4	Yes	No	Yes	Yes	15	3	150	**170**
5	Yes	No	Yes	No	21	2	225	**248**
6	Yes	No	No	No	14	9	208	**230**
7	No	No	No	No	12	4	264	**280**
8	No	Yes	No	No	12	8	270	**291**
9	Hand	No	No	No	8	6	181	**195**
Treatment mean					*13*	*5*	*216*	*233*
Significance level					*n.s*	*n.s*	*n.s*	*n.s*
SED (df=47)					*4.5*	*2.64*	*37.6*	*40.7*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Table 6. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean fruit number per size class (<55mm to >70mm) per Queen Cox tree, measured on 9 September 2004.**

Treatment					Fruit number per tree						
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Small	<55 (mm)	56-60 (mm)	61-65 (mm)	66-70 (mm)	>70 (mm)	Total
1	Yes	Yes	Yes	Yes	91	33	57	42	28	9	**261**
2	Yes	Yes	Yes	No	130	21	42	48	33	16	**289**
3	Yes	Yes	No	No	90	38	55	56	41	16	**296**
4	Yes	No	Yes	Yes	125	37	68	70	45	13	**358**
5	Yes	No	Yes	No	50	28	43	38	27	21	**208**
6	Yes	No	No	No	99	27	46	45	34	29	**280**
7	No	No	No	No	76	56	76	49	19	11	**287**
8	No	Yes	No	No	87	28	43	62	56	22	**298**
9	Hand	No	No	No	64	12	29	51	50	29	**235**
Treatment mean					*90*	*31*	*51*	*51*	*37*	*19*	*279*
Significance level					*ns*	*ns*	*ns*	*ns.*	*	*ns*	*ns*
SED (df=48)					*34.8*	*15.3*	*15.8*	*13.0*	*9.9*	*8.0*	*44.4*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Table 7. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean fruit number per size class (<55mm to >70mm) per Queen Cox tree, measured on 7 September 2005.**

Treatment					Fruit number per tree					
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	<55 (mm)	56-60 (mm)	61-65 (mm)	66-70 (mm)	>70 (mm)	Total
1	Yes	Yes	Yes	Yes	27	129	21	9	0.1	**187**
2	Yes	Yes	Yes	No	72	115	32	21	0.6	**240**
3	Yes	Yes	No	No	23	138	30	16	2.0	**209**
4	Yes	No	Yes	Yes	34	126	33	19	0.4	**212**
5	Yes	No	Yes	No	75	137	24	11	0.1	**247**
6	Yes	No	No	No	74	137	15	7	0.3	**233**
7	No	No	No	No	113	135	34	3	0.0	**285**
8	No	Yes	No	No	114	151	13	4	0.0	**282**
9	Hand	No	No	No	23	108	30	16	0.0	**178**
Treatment mean					*61.6*	*130.7*	*25.7*	*11.8*	*0.4*	*230*
Significance level					***	*n.s*	*n.s*	*	*n.s*	*n.s*
SED (df=48)					*25.8*	*32.5*	*9.8*	*5.9*	*0.70*	*40.7*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Table 8. The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean total fruit weight per size class (<55mm to >70mm) per Queen Cox tree, measured on 9 September 2004.

Treatment					Fruit weight (kg) per tree						
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Small	<55 (mm)	56-60 (mm)	61-65 (mm)	66-70 (mm)	>70 (mm)	Total
1	Yes	Yes	Yes	Yes	4.1	2.5	4.4	4.1	3.3	1.4	**19.9**
2	Yes	Yes	Yes	No	5.0	1.2	3.3	4.7	3.8	2.6	**20.5**
3	Yes	Yes	No	No	4.1	2.0	4.1	5.9	4.9	2.5	**23.5**
4	Yes	No	Yes	Yes	3.7	2.0	5.6	6.8	4.3	1.8	**26.6**
5	Yes	No	Yes	No	2.3	1.8	3.4	3.8	3.3	3.5	**18.3**
6	Yes	No	No	No	4.6	1.7	3.8	4.3	4.4	4.4	**23.3**
7	No	No	No	No	3.4	3.7	6.5	5.2	2.4	1.8	**23.0**
8	No	Yes	No	No	3.8	1.5	3.9	6.2	6.2	3.4	**24.9**
9	Hand	No	No	No	4.6	0.7	2.2	4.9	5.9	4.6	**22.9**
Treatment mean					*4.0*	*1.9*	*4.1*	*5.1*	*4.4*	*2.9*	*22.6*
Significance level					*ns*	*ns*	*ns*	*ns*	*	*ns*	*ns*
SED (df=48)					*1.29*	*0.88*	*1.46*	*1.17*	*1.19*	*1.32*	*2.61*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Table 9. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean total fruit weight per size class (<55mm to >70mm) per Queen Cox tree, measured on 7 September 2005.**

Treatment					Fruit weight (kg) per tree					
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	<55 (mm)	56-60 (mm)	61-65 (mm)	66-70 (mm)	>70 (mm)	Total
1	Yes	Yes	Yes	Yes	1.4	10.1	3.1	1.5	0.02	**16.1**
2	Yes	Yes	Yes	No	3.2	9.2	3.1	2.3	0.07	**17.9**
3	Yes	Yes	No	No	1.2	10.7	2.9	1.9	0.29	**17.0**
4	Yes	No	Yes	Yes	2.0	9.8	3.3	2.1	0.07	**17.3**
5	Yes	No	Yes	No	3.9	10.4	2.2	1.1	0.01	**17.6**
6	Yes	No	No	No	4.1	9.9	1.7	0.8	0.04	**16.5**
7	No	No	No	No	6.2	9.9	3.2	0.3	0.00	**19.7**
8	No	Yes	No	No	6.5	10.7	1.2	0.5	0.00	**18.9**
9	Hand	No	No	No	1.3	8.5	3.2	1.9	0.00	**14.8**
Treatment mean					*3.3*	*9.91*	*2.66*	*1.38*	*0.06*	*17.3*
Significance level					**	*n.s*	*n.s*	*	*n.s*	*n.s*
SED (df=47)					*1.48*	*2.25*	*1.03*	*0.68*	*0.100*	*2.85*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Fruit yield and quality at harvest in 2004

On 9 September 2004 Cox trees at East Malling were harvested on a per tree basis and placed in cold storage until weighing and grading in November. Fruit were graded into 6 classes based on diameter, i.e. 'small', less than 55mm, 56 to 60mm, 61 to 65mm, 66 to 70mm and greater than 70mm. A number of fruit were picked which had been affected by rosy apple aphid; these were deformed and allocated into the size category described as 'small'. The impacts of this rosy apple aphid outbreak are explored further in subsequent fruit yield analysis.

Fruit yield and quality data are presented in full in separate tables (see Tables 6 & 8). Whether considering fruit number or fruit weight, within a size class, there were very few statistically significant treatments differences. The only apparent significant difference was for fruit in the 66 to 70mm size class. Within this fruit size class treatments 1, 5 and 7 had fewer fruit. This may not be surprising, as treatment 7 received no dormant season pruning. In the absence of pruning the number of flowers was relatively high compared with pruned treatments, but proportionally the total number of flowers per tree contained a statistically greater number of axillary flowers (Table 2). These flowers general are known not to show the same high percentage of fruit set as spur flowers and that was the case with this experiment also (Table 4). It is particularly evident that treatment 7 showed a high proportion of abscission of fruit initially determined as set, i.e. compare between 'June' fruit set (Table 4) and harvest September (Table 6). This treatment also showed the least amount of shoot growth of all the treatments, albeit not significant (Table 15).

It is unclear why treatment 8, also unpruned during the dormant season, did not show a similar reduction in fruit number at higher size classes. This result suggests that the dormant season 'Cultar' application may have in some way benefited fruit quality. Further attention to the impact of the PGR on tree shoot regrowth may reveal beneficial impacts of 'Cultar' application on tree restricting post pruning re-growth. However, despite these differences there were no statistically significant differences with mean total yield per tree per treatment.

These differences in fruit quality are summarised below in Table 10 using fewer quality classes based more closely on commercial sizes of class 1 and class 2 fruit. Whether fruit number or fruit weight within these two size classes is used there were statistically significant treatment differences in class 1 fruit. The major differences with respect to a reduction in class 1 fruit number were apparent with treatments 1 and 7. Both treatments yielded, within class 1, just over 30 fruit per tree with a weight around 4.5 kg. It is interesting, with respect to treatment combinations, treatment 1 received, both the two pruning and 'Cultar' applications, while treatment 7 received neither pruning, nor 'Cultar' application.

As discussed above fruit growth and development was for some trees influenced by an infestation of rosy apple aphid (*Dysaphis plantaginea*), producing deformed small fruit. As this is known to impact primarily on fruit growth rather than fruit set, fruit yields were adjusted to compensate for failure of all infested fruit to express full size. This was achieved by separating all rosy apple aphid damaged fruit, at harvest, and storing them separately from normal fruit. All the damaged fruit was put into the size class described as 'small' (see Tables 6 & 8). These fruit were then counted as with the normal fruit. The total number of fruit within this 'small' class was proportionally allocated depending on the number of normal fruit within each class. The weight within each class was adjusted by multiplying the number of small fruit by the average normal fruit weight in each class and added to the original normal class total weight.

The revised fruit numbers and weight obtained by making the above assumptions are shown in Tables 12 & 13. The assumptions made as described above would have no influence on the pattern of treatment differences, only on the absolute total yield.

Table 10. The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean fruit number per size class (56-65mm and 66+mm) and fruit weight (kg) per Queen Cox tree, measured on 9 September 2004.

Treatment					Fruit number		Fruit weight	
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	56-65 mm	66+ mm	56-65 mm	66+ mm
1	Yes	Yes	Yes	Yes	99	38	8.5	4.7
2	Yes	Yes	Yes	No	90	49	8.0	6.4
3	Yes	Yes	No	No	111	57	9.9	7.4
4	Yes	No	Yes	Yes	138	58	12.4	7.2
5	Yes	No	Yes	No	81	47	7.4	6.9
6	Yes	No	No	No	91	63	8.1	8.8
7	No	No	No	No	125	31	11.7	4.2
8	No	Yes	No	No	105	78	10.1	9.6
9	Hand	No	No	No	80	78	7.2	10.5
Treatment mean					*102*	*55*	*9.25*	*7.3*
Significance level					*ns*	**	*ns*	*
SED (df=48)					*24.2*	*12.9*	*2.16*	*1.76*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Fruit yield and quality at harvest in 2005

On 7 September 2005 Cox trees at East Malling were harvested on a per tree basis and placed in cold storage until weighing and grading in November. The distribution of fruit as a number and weight to various sizes classes is shown in Tables 7 and 9 respectively, for the 2005 harvest. Despite the reduction in fruit number recorded after June drop in 2005 relative to the crop in 2004, the seasonal differences in mean treatment yield (fruit number) were less than 20%, i.e. 279 in 2004 and 230 in 2005. As in 2004, there were no statistically significant treatment difference in total fruit number, but as in 2004 the hand pruned treatment was generally the lowest. There was however a statistically significantly larger number of small fruit within the <55m class associated with treatments 7 and 8. These non-pruned trees produced considerably more fruit than treatments 1,3,4, and 9 in the <55mm size class (which were all dormant season pruned) and fewer fruit in 66-70 class and no fruit in >70mm class.

Table 11. Mean fruit weight and number per tree for fruit 66+mm and 56-65mm diameter. The effects of dormant and petal fall pruning and dormant and petal fall application of plant growth regulator 'Cultar' on the harvest Queen Cox picked on 7 September 2005.

Treatment					Fruit number per tree		Fruit weight per tree	
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	56-65 mm	66+ mm	56-65 mm	66+ mm
1	Yes	Yes	Yes	Yes	129	7	13.2	1.5
2	Yes	Yes	Yes	No	147	21	12.3	2.4
3	Yes	Yes	No	No	168	18	13.6	2.2
4	Yes	No	Yes	Yes	159	19	13.1	2.1
5	Yes	No	Yes	No	161	11	12.6	1.2
6	Yes	No	No	No	152	8	11.6	0.8
7	No	No	No	No	169	3	13.1	0.3
8	No	Yes	No	No	164	4	11.9	0.5
9	Hand	No	No	No	138	16	11.7	1.9
Treatment mean					154	12	12.6	1.4
Significance level					n.s	*	n.s	*
SED (df=48)					35.1	6.1	4.87	1.47

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

A comparison of fruit number per tree made in 2005 after June drop and at final harvest shows that little further fruit abscission occurred during this period in 2005 (compare Tables 5 and 7). This was different from what occurred in 2004, where the post-June drop was greater (compare 4 and 6). An explanation for this apparent difference in post-June drop, between years, does not seem to be evident at the treatment level so it would appear to be a seasonal difference. It was noted that when the post-June drop counts were being carried out in 2005 that some trees had secondary blossom. Queen Cox does produce secondary blossom, but these are most frequently in axillary positions and therefore do not set much fruit. But at least in this case some of this fruit does appear to have set initially and be retained until harvest in 2005.

As with the total number of fruit there were no statistically significant mean treatment differences in total yield per tree in 2005 (Table 9), as was the case in 2004. The total mean weight of fruit was however lower in 2005 (17.3 kg per tree) compared to 2004 (22.6 kg per tree). Similarly to the fruit number analysis there were statistically significant differences in the fruit weight within size classes 66-70 mm and <55mm, again treatments 7 and 8 showing greater weights in the small size class and less weight in the larger category.

Table 12. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean fruit number per tree per size class (<55mm to >70mm) per Queen Cox tree, measured on 9 September 2004. Small misshapen fruit (attacked by rosy apple aphid) have been proportionally incorporated into each size category.**

Treatment					Fruit number per tree					
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	<55 (mm)	56-60 (mm)	61-65 (mm)	66-70 (mm)	>70 (mm)	Total
1	Yes	Yes	Yes	Yes	54	85	65	42	15	**261**
2	Yes	Yes	Yes	No	41	80	85	60	24	**289**
3	Yes	Yes	No	No	54	79	82	57	24	**296**
4	Yes	No	Yes	Yes	64	113	103	62	17	**358**
5	Yes	No	Yes	No	35	55	54	37	27	**208**
6	Yes	No	No	No	40	70	73	55	42	**280**
7	No	No	No	No	79	106	64	25	14	**287**
8	No	Yes	No	No	37	63	87	82	30	**298**
9	Hand	No	No	No	15	38	70	69	42	**235**
Treatment mean					*47*	*76*	*76*	*54*	*26*	*279*
Significance level					*ns*	*	*ns*	*	*ns*	*ns*
SED (df=48)					*21.9*	*21.06*	*18.6*	*15.8*	*11.97*	*44.4*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Table 13. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean total fruit weight per tree per size class (<55mm to >70mm) per Queen Cox tree, measured on 9 September 2004. Small misshapen fruit (attacked by rosy apple aphid) have been proportionally incorporated into each size category.**

Treatment					Fruit weight (kg) per tree					
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	<55 (mm)	56-60 (mm)	61-65 (mm)	66-70 (mm)	>70 (mm)	Total yield
1	Yes	Yes	Yes	Yes	4.1	6.7	6.3	4.9	2.2	**24.3**
2	Yes	Yes	Yes	No	2.3	6.1	8.3	6.9	3.8	**27.3**
3	Yes	Yes	No	No	2.8	5.8	8.3	9.9	3.7	**27.5**
4	Yes	No	Yes	Yes	3.6	9.3	10.1	7.5	2.4	**32.8**
5	Yes	No	Yes	No	2.2	4.5	5.3	4.6	4.7	**21.2**
6	Yes	No	No	No	2.5	5.7	7.0	7.0	6.3	**28.5**
7	No	No	No	No	5.3	8.9	7.0	3.0	2.2	**26.5**
8	No	Yes	No	No	2	5.6	8.6	8.7	4.6	**29.5**
9	Hand	No	No	No	1.0	3.0	6.7	8.2	6.7	**25.5**
Treatment mean					*2.9*	*6.2*	*7.5*	*6.4*	*4.1*	*27.0*
Significance level					*ns*	*ns*	*ns*	*	*ns*	*ns*
SED (df=48)					*1.30*	*1.99*	*1.68*	*1.76*	*1.90*	*3.70*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

As carried out previously with fruit and number yields, fruit quality assessments were simplified by allocating fruit to either class 1 or class 2 (Table 14). This proportional allocation of yield produced no significant statistical changes that were not present in the original analysis not taking into account the rosy apple aphid (*Dysaphis plantaginea*) infestation. Again there were statistically significant treatment differences for class 1 fruit. Hand pruned trees (treatment 9) had the largest number and weight of 66+mm fruit, while the no punned treatment (7) had the smallest number and weight. However, several of the dormant season simulated mechanical pruning treatments (2, 3, 4 & 6) yielded similar class 1 fruit and combined class 1 and class 2 fruit as treatments 7, 8 and 9.

Table 14. The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean fruit number per size class (56-65mm and +66mm) and fruit weight (kg) per Queen Cox tree, measured on 9 September 2004. Small misshapen fruit (attacked by rosy apple aphid) have been proportionally incorporated into size categories for weight and number.

Treatment					Number of fruit per tree		Fruit weight per tree	
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	56-65 mm	66+ mm	56-65 mm	66+ mm
1	Yes	Yes	Yes	Yes	150	57	13.0	7.1
2	Yes	Yes	Yes	No	165	84	14.4	10.6
3	Yes	Yes	No	No	161	81	14.2	10.6
4	Yes	No	Yes	Yes	215	79	19.4	9.9
5	Yes	No	Yes	No	109	64	9.8	9.2
6	Yes	No	No	No	143	97	12.7	13.3
7	No	No	No	No	170	38	16.0	5.2
8	No	Yes	No	No	149	112	14.2	13.3
9	Hand	No	No	No	108	111	9.7	14.8
Treatment mean					*152*	*80*	*13.7*	*10.5*
Significance level					*ns*	*	*	*
SED (df=48)					*32.2*	*21.3*	*2.88*	*2.70*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Shoot growth in 2004-05

Figure 4 shows dramatic differences in the amount of wood removed by conventional tree pruning as compared with simulated mechanical pruning. This is particularly true, in these photographs, for shoot growth above the tree stake. Quantitative measurements of shoot growth for treated Queen Cox are shown in Table 15. For Queen Cox, despite variation between treatments, the variation within treatments was sufficient to exclude any statistically significant treatment differences in total shoot growth per tree (Table 15). There were, however, highly significant differences in mean average shoot length. Treatments that received no dormant season pruning (treatments 7 and 8) had significantly shorter average shoot lengths. This, combined with a generally smaller number of new shoots contributed to small total shoot growth for these two treatments, albeit that they were not significantly different from the other treatments.

Table 15. The number of new shoots (>5cm), average new shoot length, and total new shoot growth occurring in the growing season of 2004 for Queen Cox per tree. Measurements were made in January 2005.

Treatment					Shoot parameter		
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Number of new shoots per tree	Average shoot length (cm) per tree	Total shoot growth (m) per tree
1	Yes	Yes	Yes	Yes	79	21	**16.9**
2	Yes	Yes	Yes	No	110	23	**29.0**
3	Yes	Yes	No	No	111	26	**29.9**
4	Yes	No	Yes	Yes	114	24	**27.4**
5	Yes	No	Yes	No	123	24	**32.0**
6	Yes	No	No	No	101	22	**24.7**
7	No	No	No	No	74	16	**13.6**
8	No	Yes	No	No	86	19	**16.4**
9	Hand	No	No	No	82	28	**23.3**
Treatment mean					*98*	*23*	*23.7*
Significance level					*ns*	***	*ns*
SED (df=48)					*20.8*	*2.1*	*6.70*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Results

Bramley's Seedling planting at Figgis' farm

Figure 3. Bramley's Seedling trees at Figgis' Farm shortly after the application of pruning treatments in spring 2004.

Figure 4. Bramley's Seedling trees at Figgis' Farm during the cropping season of 2005.

Effects of pruning on flower number in 2004

As evident with the Queen Cox trees at EMR there were marked differences between treatments 1 to 8 and the hand pruned trees (Table 16). Hand pruning (treatment 9) significantly reduced the number of flowers in spur positions. The non-pruned trees produced the most flowers, particularly with respect to treatments 1 to 5, which all received dormant season pruning.

There were significant differences in the number of flower clusters between the applied treatments in 2004 (Table 16). The hand pruned treatment (treatment 9) produced the lowest total number of flower clusters however this result was not significantly different from treatment 3. The no prune treatments (treatments 7 and 8) produced some of the greatest number of flower bud clusters but these results were not significantly different from two of the hedge cutter simulation treatments (treatments 4 and 6).

For the treatment mean, axillary flower buds only contributed 5% to the total flower bud cluster number, terminal buds contributed 20% whereas spur flower clusters made up the largest portion of the total number, contributing 75%.

Table 16. The effects of pruning during the dormant season (March and April) and concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean flower cluster number per Bramley's Seedling tree, measured on 30 April 2004.

Treatment			Number of flower clusters per tree			
#	Dormant prune	Dormant PGR	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	63	25	270	**358**
2	Yes	Yes	64	15	290	**369**
3	Yes	Yes	47	13	242	**302**
4	Yes	No	88	19	275	**381**
5	Yes	No	66	16	253	**335**
6	Yes	No	85	27	309	**421**
7	No	No	96	20	310	**426**
8	No	Yes	78	17	324	**419**
9	Hand	No	58	15	188	**262**
Treatment mean			*72*	*19*	*274*	*364*
Significance level			*ns*	*ns*	**	***

SED (df=48)	*15.8*	*6.8*	*33.6*	*40.6*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Effects of pruning on flower number in 2005

The mean number of flower bud clusters per tree measured on 16 May 2005, was reduced in 2005 (328) compared to 2004 (364), however, the mean number of fruit per tree post June drop but prior to thinning,18 July 2005, was increased in 2005 (257) compared to 2004 (119). The distribution of flower buds relative to terminal, axillary and spur positions was approximately equal in both 2004 and 2005 (Table 17).

Table 17. The effects of pruning during the dormant season (March and April) and concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean flower cluster number per Bramley's Seedling tree, measured on 16 May 2005.

Treatment			Number of flower clusters per tree			
#	Dormant prune	Dormant PGR	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	82	8	186	**276**
2	Yes	Yes	94	11	244	**349**
3	Yes	Yes	102	13	220	**335**
4	Yes	No	109	16	280	**405**
5	Yes	No	96	11	241	**347**
6	Yes	No	72	7	146	**225**
7	No	No	114	13	244	**370**
8	No	Yes	133	11	265	**409**
9	Hand	No	72	14	151	**237**
Treatment mean			*97*	*11*	*220*	*328*
Significance level			***	*n.s.*	**	**
SED (df=48)			*13.6*	*3.54*	*38.4*	*49.2*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Effects of pruning on fruit number in 2004

Fruit measured post June drop (Table 17) showed a set of around 1 fruit per 3 flowers. More specifically it show that 1 in 4 flower buds in terminal position set a fruit, while most flowers in axillary positions set 1 fruit, and spurs only set 1 fruit 2.7 clusters. Although the greatest number of fruit and buds was lost from the spur position, this position still produced the predominant amount of fruit. Table 17, also shows no significant differences for total fruit measured on 12 July 2004.

Table 18. The effects of pruning during the dormant season (March and April), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean fruit number per flower position (terminal, axillary and spur) per Bramley's Seedling tree, measured on 12 July 2004.

Treatment					Number of fruit per tree			
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	Yes	Yes	21	10	93	**123**
2	Yes	Yes	Yes	No	24	8	85	**117**
3	Yes	Yes	No	No	19	13	73	**105**
4	Yes	No	Yes	Yes	24	7	69	**100**
5	Yes	No	Yes	No	23	8	77	**108**
6	Yes	No	No	No	30	13	88	**131**
7	No	No	No	No	31	12	99	**141**
8	No	Yes	No	No	31	14	86	**132**
9	Hand	No	No	No	24	7	78	**109**
Treatment mean					*25*	*10*	*83*	*119*
Significance level					*ns*	*	*ns*	*ns*
SED (df=48)					*5.0*	*2.6*	*12.6*	*15.4*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Effects of pruning on fruit number in 2005

In 2005, relative to 2004, there was an increase in fruit number from the terminal and spur positions, which increased from 25 to 66 and 83 to 181 respectively (Table 19). This shows the predominant amount of fruit which arises from spur positions. In both 2004 and 2005 fruit in the spur position accounted for 70% of the fruit, in 2004 21% of fruit was found in the terminal position and 9% in the axillary position whereas in 2005, 25% of the fruit was found in the terminal position and 5% in the axillary position.

Particularly in 2005 the two treatments receiving no winter pruning resulted in the greatest mean number of apples per tree post June drop and in 2005 the hand pruning treatment resulted in the least number of fruit. There was a significant difference in the number of terminal, axillary and spur fruit between hand prune and no prune treatments. From the trees pruned by mechanical pruning simulation four treatments were significantly different from both the hand prune (minimum fruit number) and no prune (maximum fruit number) treatments for total fruit post June drop (Table 19).

Table 19. The effects of pruning during the dormant season (March and April), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean fruit number per flower position (terminal, axillary and spur) per Bramley's Seedling tree, measured on 18 July 2005.

Treatment					Number of fruit per tree			
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	Yes	Yes	63	7.4	179	**249**
2	Yes	Yes	Yes	No	74	11.3	217	**303**
3	Yes	Yes	No	No	62	12.3	166	**241**
4	Yes	No	Yes	Yes	68	11.6	176	**256**
5	Yes	No	Yes	No	59	9.4	155	**224**
6	Yes	No	No	No	54	6.6	155	**216**
7	No	No	No	No	80	11.6	225	**316**
8	No	Yes	No	No	78	12.0	218	**307**
9	Hand	No	No	No	52	8.0	136	**197**
	Treatment mean				*66*	*10.0*	*181*	*257*
	Significance level				***	**	***	***
	SED (df=48)				*7.14*	*2.007*	*17.39*	*23.5*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Fruit yield and quality at harvest in 2004

Table 20 shows the distribution of fruit size in 5mm intervals and shows no statistically significant differences. This data are then summarised in Table 22 where again no significant differences are observed.

In 2004 there was no discernable difference in the <80mm, 81-100mm and 101mm+ size classes between the treatments applied. In 2005 there were significant differences between hand prune and no prune treatments in each of the <80mm, 81-100mm and 101mm+ size classes (Table 20). Treatment 9, hand prune, has a significantly greater number of fruit in the 81-100mm size class than any other treatment and a significantly smaller number of fruit in the <80mm size class than any other treatment. The no prune treatment produced fruit with the smallest quantity of fruit in the 81-100mm size class, but these results were not significantly different from most of the hedge cutter simulation treatments. Although not statistically different from a number of other treatments, treatment number 5, as a mechanical simulation, gave the largest percentage of fruit in the 81-100mm size class after treatment 9 (hand pruned).

Fruit yield and quality at harvest in 2005

Between June drop and harvest in 2005 the mean number of fruit per tree fell from 257 to 161, a fall of 37% with a range of 25% to 42% across the treatments (Tables 18 and 20).

Measurements prior to harvest, 17 August 2005 echoed the results post June drop with the hand pruned treatment having the least number of fruit (124) and the unpruned trees having the greatest quantity of fruit (183 and190) (Table 23). The difference between the unpruned and hand pruned trees was significant but only two treatments (1 and 4) were significantly different from both of the hand prune and no prune treatments.

The combination of data from different size classes in Tables 21 and 22 show that for Bramley in 2005, as mean number of fruit per tree increases, fruit size decreases.

Table 20. The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on percentage of fruit number per size class (<65mm to +101mm) per Bramley's Seedling tree, measured on 9 September 2004.

Treatment					Percentage of number of fruit in each size class per tree								
#	Dormant prune?	Dormant PGR?	Petal fall prune?	Petal fall PGR?	<65 mm	66-70 mm	71-75 mm	76-80 mm	81-85 mm	86-90 mm	91-95 mm	96-100 mm	101+ mm
1	Yes	Yes	Yes	Yes	1.1	3.4	6.3	17.1	16.6	30.3	17.1	5.1	2.9
2	Yes	Yes	Yes	No	1.1	2.9	5.1	17.1	20.6	28.0	18.3	5.7	1.1
3	Yes	Yes	No	No	3.0	4	5.4	13.4	24.9	29.4	13.4	5.4	1.3
4	Yes	No	Yes	Yes	8.0	2.9	9.7	13.1	26.3	22.3	14.3	2.9	0.6
5	Yes	No	Yes	No	1.7	4.0	8.6	22.3	18.3	25.7	16.0	2.3	1.1
6	Yes	No	No	No	3.4	6.9	9.7	14.3	18.3	30.9	12.0	2.9	1.7
7	No	No	No	No	0.6	1.7	4.0	16.0	22.9	30.3	21.1	2.9	0.6
8	No	Yes	No	No	0.6	4.0	6.3	13.1	23.4	34.3	11.4	5.7	1.1
9	Hand	No	No	No	2	2.9	6.0	14.3	21	28.4	19.9	4.6	1.1
Treatment mean					*2.4*	*3.6*	*6.8*	*15.7*	*21.3*	*28.8*	*16.0*	*4.2*	*1.3*
Significance level					*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
SED (df=48)					*2.78*	*1.92*	*2.61*	*4.50*	*4.82*	*5.29*	*3.38*	*2.15*	*1.20*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Table 21. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on percentage of fruit number per size class (<65mm to +101mm) per Bramley's Seedling tree, measured on 17 August 2005.**

Treatment					Percentage of number of fruit in each size class per tree								
#	Dormant prune?	Dormant PGR?	Petal fall prune?	Petal fall PGR?	<65 mm	66-70 mm	71-75 mm	76-80 mm	81-85 mm	86-90 mm	91-95 mm	96-100 mm	101+ mm
1	Yes	Yes	Yes	Yes	5.1	6.3	18.9	17.1	18.3	20.0	9.1	4.0	1.1
2	Yes	Yes	Yes	No	4.0	7.4	17.7	20.0	18.9	16.6	5.7	6.9	2.9
3	Yes	Yes	No	No	1.7	8.0	13.7	23.4	19.4	18.3	9.7	3.4	2.3
4	Yes	No	Yes	Yes	2.3	4.6	17.7	24.6	14.3	20.6	9.7	4.6	1.7
5	Yes	No	Yes	No	3.4	8.6	12.6	17.7	21.1	20.6	10.3	3.4	2.3
6	Yes	No	No	No	4.6	9.1	12.6	20.0	22.3	18.3	8.0	4.0	1.1
7	No	No	No	No	8.6	8.0	16.0	22.9	25.7	12.0	4.6	1.7	0.6
8	No	Yes	No	No	2.9	8.6	18.9	28.0	21.7	12.6	5.1	1.3	0.0
9	Hand	No	No	No	4.0	3.4	11.4	12.6	17.7	30.3	9.7	7.4	3.4
Treatment mean					*4.1*	*7.1*	*15.5*	*20.7*	*19.9*	*18.8*	*8.0*	*4.2*	*1.71*
Significance level					*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	*n.s.*	*n.s.*	*n.s.*
SED (df=48)					*2.09*	*3.53*	*4.21*	*4.98*	*5.21*	*4.49*	*3.53*	*2.50*	*1.59*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1% (**) or 0.1% (***) level.

Table 22. The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator ‘Cultar’, to pruning wounds, on mean fruit weight in each size class (<80mm, 81-100mm and 101+mm diameter) expressed as a percentage of the total weight (kg) per Bramley’s Seedling tree, measured on 9 September 2004.

Treatment					Percentage of number of fruit in each size class		
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	<80mm	81-100mm	101mm+
1	Yes	Yes	Yes	Yes	28.0	69.1	2.9
2	Yes	Yes	Yes	No	26.3	72.6	1.1
3	Yes	Yes	No	No	25.9	73.1	1.3
4	Yes	No	Yes	Yes	33.7	65.7	0.6
5	Yes	No	Yes	No	36.6	62.3	1.1
6	Yes	No	No	No	34.3	64.0	1.7
7	No	No	No	No	22.3	77.1	0.6
8	No	Yes	No	No	24.0	74.9	1.1
9	Hand	No	No	No	25.1	73.9	1.1
Treatment mean					*28.5*	*70.3*	*1.29*
Significance level					*ns*	*ns*	*ns*
SED (df=48)					*5.97*	*5.71*	*1.20*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1%(**) or 0.1% (***) level.

Table 23. The effects of dormant and petal fall pruning and dormant and petal fall application of plant growth regulator ‘Cultar’ on the number of Bramley fruit prior to harvest, measured on 17 August 2005.

Treatment					
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Total number of fruit per tree
1	Yes	Yes	Yes	Yes	**147**
2	Yes	Yes	Yes	No	**175**
3	Yes	Yes	No	No	**180**
4	Yes	No	Yes	Yes	**155**
5	Yes	No	Yes	No	**166**
6	Yes	No	No	No	**128**
7	No	No	No	No	**183**
8	No	Yes	No	No	**190**
9	Hand	No	No	No	**124**
Treatment mean					*160.8*
Significance level					**
SED (df=48)					*19.02*

Significance levels are non-significant (n.s.) or significant at the 5 (*), 1(**) and 0.1% (***) level.

Table 24. The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on mean fruit weight in each size class (<80mm, 81-100mm and 101+mm diameter) expressed as a percentage of the total weight (kg) per Bramley's Seedling tree, measured on 17 August 2005.

Treatment					Percentage of number of fruit in each size class		
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	<80 mm	81-100 mm	>101 mm
1	Yes	Yes	Yes	Yes	47.4	51.4	1.1
2	Yes	Yes	Yes	No	49.1	48.0	2.9
3	Yes	Yes	No	No	46.9	50.9	2.3
4	Yes	No	Yes	Yes	49.1	49.1	1.7
5	Yes	No	Yes	No	42.3	55.4	2.3
6	Yes	No	No	No	46.3	52.6	1.1
7	No	No	No	No	55.4	44.0	0.6
8	No	Yes	No	No	58.3	41.7	0.0
9	Hand	No	No	No	31.4	65.1	3.4
Treatment mean					*47.4*	*50.9*	*1.71*
Significance level					*n.s.*	*n.s.*	*n.s.*
SED (df=48)					*8.87*	*8.83*	*1.59*

Statistical analysis was carried using ANOVA with significance levels determined as, non-significant (ns), significant at 5% (*), 1%(**) or 0.1% (***) level.

Table 25. The number of new shoots (>5cm), average new shoot length, and total new shoot growth occurring in the growing season of 2004 per tree Bramley's Seedling, measurements were made January 2005.

Treatment					Shoot parameter		
#	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Number of new shoots per tree	Average shoot length (cm) per tree	Total shoot growth (m) per tree
1	Yes	Yes	Yes	Yes	183	33	**61.1**
2	Yes	Yes	Yes	No	203	34	**71.5**
3	Yes	Yes	No	No	216	37	**78.8**
4	Yes	No	Yes	Yes	210	38	**81.0**
5	Yes	No	Yes	No	194	37	**72.9**
6	Yes	No	No	No	198	35	**73.8**
7	No	No	No	No	218	34	**78.1**
8	No	Yes	No	No	259	34	**88.7**
9	Hand	No	No	No	168	39	**66.4**
Treatment mean					*206*	*36*	*74.7*

Significance level	*ns*	*ns*	*ns*
SED (df=48)	*27.7*	*32.4*	*15.0*

Shoot growth in 2004-05

Quantitative shoot growth within the Bramley experiment failed to show any statistically significant differences in either shoot number per tree, mean average shoot length or total shoot growth per tree (Table 25). Mean average shoot length was in particular very similar with respect to treatment, whereas the number of shoots was apparently more variable.

Effects of high pressure water jets on flower bud removal

It can be seen that a high pressure water jet was an effective blossom thinner (Table 25 and 26). The impact of the different applications made on 15 and 27 May followed a similar trend, with round 30 to 50% of all flowers being removed. However the application applied on 5 May was more variable. At this application the treatment applied as a two second burst at a distance of 10cm from the buds resulted in no bud loss. This result is unexplained.

A

B

Figure 5. **Effects of pressure washing on flower removal on Queen Cox trees at EMR. Figure A, prior to pressure treatment and B, post pressure treatment. An effective number of flowers**

have been removed by the pressure treatment, particularly with respect to open flowers.

Table 25. **The effects of a high pressure water jet on flower thinning of Queen Cox trees at EMR. Initial and final flower numbers are shown and the number removed as percentage of the original flower number. Thinning was carried out on three occasions during flowering (5, 15 and 27 May 2004)**

5 May

Distance of nozzle (cm)	Flower cluster number before spray	Flower cluster number after spray	Percentage change in flower cluster number
5	45	28	-40
10	50	39	-21
15	54	43	-20
10 Continuous	56	49	-12

15 May

Distance of nozzle (cm)	Flower cluster number before spray	Flower cluster number after spray	Percentage change in flower cluster number
5	47	36	-24
10	51	38	-25
15	44	37	-17
10 Continuous	38	34	-6

27 May

Distance of nozzle (cm)	Flower cluster number before spray	Flower cluster number after spray	Percentage change in flower cluster number
5	25	12	-54
10	44	21	-52
15	40	25	-38
10 Continuous	37	30	-20

Table 26. The effects of a high pressure water jet on flower thinning of Bramley's Seedling trees at grower's farm, Faversham. Initial and final flower numbers are shown and the number removed as percentage of the original flower number. Thinning was carried out on three occasions during flowering (5, 15 and 27 May 2004)

5 May

Distance of nozzle (cm)	Flower cluster number before spray	Flower cluster number after spray	Percentage change in flower cluster number
5	48	20	-58
10	23	23	0
15	33	18	-45
10 Continuous	36	23	-36

15 May

Distance of nozzle (cm)	Flower cluster number before spray	Flower cluster number after spray	Percentage change in flower cluster number
5	36	24	-34
10	34	19	-40
15	46	32	-29
10 Continuous	39	37	-6

27 May

Distance of nozzle (cm)	Flower cluster number before spray	Flower cluster number after spray	Percentage change in flower cluster number
5	10	6	-37
10	8	4	-54
15	15	9	-43
10 Continuous	12	10	-20

Conclusions

Simulated mechanical pruning

Pruning during the dormant season is used to reduce the number of flower buds that the tree would naturally produce, in order to improve the 'quality' of the fruit that remains. Traditionally, the process of pruning is based on intelligent decision making and labour intensive field operations to achieve the optimal number of flowers and fruit in relation various factors. We show here, very clearly, the marked and expected differences between the traditional hand pruning and our attempts to determine if the operation can be simplified to enable mechanisation. Hand pruning results in a greater reduction in flower buds than mechanical pruning as hand pruning removes wood from around the entire periphery of the tree, as well as, within its canopy. Simulated mechanical pruning, however as carried out here, only removes wood parallel to the grass strip leaving wood between trees, within the row, intact. With time, trees that are continually pruned in this fashion will merge into a tree wall. This has already become apparent with the Queen Cox trees within these experiments, which when the work started were distinctly separate trees. This may have considerable negative impacts on the development and quality of fruit that grows within the wall. It has always been envisaged that this initial simulation of mechanical pruning was intend to test and evaluate a principle.

To develop the work further would require studying the best ways to apply mechanical pruning to trees that have been grown to facilitate the application of mechanical operations from planting, rather than through the conversion of existing orchard growing systems. Such plantings are envisaged as likely requiring different tree supports systems that would enable the mechanical pruning operations to be achieved effectively by removal of wood from within the tree, not just the periphery, as with these initially experiments. The removal of wood from within the tree is suggested as a particularly important goal for the success of any mechanical approach. In the experiments carried out here with Queen Cox, for example, the conventional planting system and tree training to a central leader shows that a considerable amount of wood and fruit will develop within the tree that conventional pruning removes annually. Even after only two years the amount of wood and flower within the tree can be considerable, as shown in some of the figures within this report. This issue may however only require attention, on a less frequent cycle of pruning, than current annual removal. But as yet, we have insufficient information to be able to recommend the most appropriate scheduling frequency of such work.

Simulated mechanical pruning of Queen Cox

In general terms, simulated mechanical pruning of Queen Cox has been shown to be beneficial. That is to say, we have not been able to show any consistent negative impacts on yield or fruit quality that can be linked to this method of pruning. However, these experiments have to be considered as short-term with respect to the productive life of an orchard. In relative terms all the simulated mechanical pruning treatments have produced larger yields than comparable hand pruned treatments. In some case trees which have not been subject to any dormant season pruning have produced even more fruit than those mechanically pruned, or hand pruned. Again in regard to the short-term nature of these experiments an argument could be put forward to suggest that the higher fruit number associated with the non-pruned trees was expected and may well be unsustainable. High fruit numbers may also impact on the seasonal differences in cropping with some varieties showing a tendency towards biennial bearing. Evidence is already apparent that cropping at these high numbers impacts of fruit size, inducing an increase in the proportion of fruit within the smaller size classes. Extrapolation may conclude that this situation will become worst as the amount of wood and shaded fruit increases with time. Again this supports the idea that a tree training system suitable for mechanical pruning operations must include the means to remove wood and flowers from within the tree.

Simulated mechanical pruning effects on shoot growth of Queen Cox

Shoot growth in general terms, as yet, has shown very little quantitative treatment response for Queen Cox. This is true for the number of shoot per tree, the mean average shoot length per tree and the total shoot growth for 2004 per tree. It is perhaps not overly surprising that statistically significant differences in shoot growth were not apparent after a single year's growth. Visual evidence (dormant season 2005-06), not quantified within this project suggests that shoot growth has been extensive and individual trees are become less easy to discern. This is accompanied by denser branches and potential fruit production within the tree, which will not be removed by our simulated mechanical pruning operations, as evaluated in this project.

Equally important are problems associated with inappropriate pruning regimes as they are likely to compound with time. For example, a no, or limiting pruning regime is likely to impact on flower bud development and quality in subsequent growing seasons. As yet we do not know how important these carry over response on flowering, yield and fruit quality will be. We are well aware from more conventional growing systems that these are important issues.

Simulated mechanical pruning of Bramley's Seedling

Bramley's Seedling data for 2004 shows that in the first year although the number of flower clusters was affected by treatment, there is no effect on fruit number or fruit size from any of the treatments. Fruit was produced predominantly in the spur position with 70% of the fruit occurring here. In the second season of the trial, flower number was shown to be affected by treatment with hand pruning producing the least number of flowers. In 2005 again 70% of the fruit was produced from the spur position but the mean number of fruit per tree across the treatments was increased relative to 2004 from 119 to 257.

Treatment was shown to have a significant effect on fruit number and size with hand pruning (treatment 9) producing the least number of fruit, but the greatest percentage of fruit in the 81-100mm size class. The unpruned trees (treatments 7 and 8) produced the greatest number of fruit per tree, but also produced the greatest percentage of fruit in the <80mm size class. The simulated mechanical pruning resulted in fruit number per tree and size of fruit falling between these ranges. Of these treatments, treatment 3 produced the greatest total number of fruit per tree and treatment 5 the greatest proportion of fruit in the 81-100mm size class.

Simulated mechanical pruning effects on shoot growth of Bramley's Seedling

Quantitative measurements of shoot growth made in the dormant season of 2004-05 suggest that as would be expected hand pruned reduced total shoot growth relative to most of the other treatments particularly the no pruned treatments. However, more interesting is the greater reduction in shoot growth achieved with treatment 1, where both pruning times and PGR applications were made. Again some caution has to be used with this information as this is from only 1 year's data and impacts over much longer time periods need to be considered.

Thinning flowers of Queen Cox and Bramley's Seedling with high pressure water jet

It can be seen from the results of applications of high pressure water jets to flowers of both Queen Cox and Bramley's Seedling that this method is effective at flower thinning. The effectiveness of this technique is dependant upon timing of the application, distance of the nozzle from the buds and the jet type, either a pulse of two seconds or a sustained burst travelling along the branch. In Bramley between 0 and 58% of the flowers were removed with the greatest and least thinning effect occurring on 5 May. In the case Queen Cox, 6 to 54% of the flowers were removed with the greatest flower removal occurring on 27 May and the least flower removal occurring on 15 May.

Although this appears to be an effective technique, the methodology of commercial application still needs to be determined. As an apple tree is a three dimensional shape with flower occurring all the way around the tree and the movement of a sprayer up a row is planar, the flowers nearest the sprayer will be effectively thinned whereas the flowers nearer the centre of the row will not be effectively thinned due to their distance from the nozzles of the sprayer. This will cause fewer apples to be found on the extremities of the tree in the region where higher light levels impact and a higher proportion of the apples to be found closer to the centre of the tree where there is less available light. This will have the overall effect of producing a greater proportion of fruit with poor colour due to the lower light levels. Further research is therefore needed to develop a commercial method of applying this effective technique. Again this approach will need to be developed in conjunction with a growing system that enables access to flowers within the tree that should be removed.

Appendix I

Queen Cox planting at EMR

Figure 6. A composite image of the Queen Cox orchard used at East Malling Research (winter 2003-04. On the left can be seen a row of trees conventionally pruned by hand, on the right is the next row which includes blocks of experimental trees containing all of the nine experimental treatments.

Figure 7.

Queen Cox trees in the dormant season 2004-05.

Treatment 7

No pruning in the dormant season or at petal fall.

No applications of PGR (Cultar) in the dormant season or at petal fall.

Figure 8.

Queen Cox trees in the dormant season 2004-05.

Treatment 8

No pruning in the dormant season or at petal fall.

PGR applications after dormant season pruning, but none at petal fall

Figure 9.

Queen Cox trees in the dormant season 2004-05.

Treatment 3

Pruning in the dormant season, but none at petal fall.

PGR applications after dormant season pruning

Figure 10.

Queen Cox trees in the dormant season 2004-05.

Treatment 6

Pruning in the dormant season, but none at petal fall.

No PGR applications in the dormant season or at petal fall

Pictorial examples of some of the treatment influences are shown in Figures 5 to 8, when the trees were dormant in early 2005. The no pruning treatments (Figures 5 and 6, treatments 7 and 8) show a large amount of growth in the top of the tree above the support post. The removal of this top growth, by pruning, is clearly evident in Figures 7 and 8 (treatments 3 and 6). Differences in response to the application and timing of PGR are less clearly shown in these photographs.

Figure 11. Examples of hand pruned (left) and unpruned (right) Queen Cox trees are shown during the dormant season of 2004-05.

Appendix II

Bramley's Seedling planting at Figgis' Farm

Figure 12. Examples of hand pruned (left) and unpruned (right) Bramley's Seedling trees are shown during the cropping season of 2005.

Appendix III

General comments regarding the contents of appendix

As requested by HDC technical staff data showing treatment variation has also been included in this report. To avoid extremely large complicated tables these data are now presented in new separate tables within this appendix. All secondary tables are numbered as in the main body of the report, with the exception that their number is followed by the letter a.

These requested tables show the direct variation (minimums and maximums) between trees. Some of this variation would have at least been partially dealt with by the experimental design and the treatment blocking. This blocking was included in the original ANOVA analyses as presented in the main tables within the body of this report. The original analyses, with the 9 treatments, used a combined ANOVA taking the blocking into account across all treatments. We were well aware when designing these experiments that tree vigour and environment were likely confounding variables and good statistical practice was to ensure blocks were used to reduce their impact on identifying statistical treatment differences.

We have again employed and consulted with a Biometrician, Dr Gillian Arnold, for advice and she has again indicated that her preferred method of analysis must be the original ANOVA which includes the treatment blocking. Therefore the tables within these appendices do not include additional statistical analyses.

Table 2a. **The effects of pruning during the dormant season (March) and concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean flower cluster number per Queen Cox tree, measured over 20-23 April 2004.**

	Treatment		Number of flower clusters			
	Dormant prune	Dormant PGR*	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	1-16	0-25	128-501	**130-514**
2	Yes	Yes	1-10	1-6	133-450	**145-464**
3	Yes	Yes	4-30	0-55	87-469	**91-554**
4	Yes	No	2-59	0-25	225-505	**234-513**
5	Yes	No	0-13	0-8	122-376	**122-391**
6	Yes	No	1-16	0-14	117-325	**147-332**
7	No	No	7-37	0-154	87-673	**98-864**
8	No	Yes	3-56	1-104	127-375	**137-535**
9	Hand	No	2-32	0-69	112-301	**122-338**

Table 4a. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean fruit number per flower position (terminal, axillary and spur) per Queen Cox tree, measured over 10-16 June 2004.**

	Treatment				Number of fruit			
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	Yes	Yes	0-9	0-5	105-342	**229-343**
2	Yes	Yes	Yes	No	0-3	0-17	169-427	**189-430**
3	Yes	Yes	No	No	4-12	0-21	84-537	**89-545**
4	Yes	No	Yes	Yes	0-27	0-47	277-517	**281-517**
5	Yes	No	Yes	No	0-9	0-10	95-408	**98-410**
6	Yes	No	No	No	0-6	0-23	160-429	**167-439**
7	No	No	No	No	0-18	0-80	217-700	**222-798**
8	No	Yes	No	No	0-21	0-26	208-395	**216-442**
9	Hand	No	No	No	0-33	0-37	198-396	**212-466**

Table 6a. The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean fruit number per size class (<55mm to >70mm) per Queen Cox tree, measured on 9 September 2004.

	Treatment				Fruit number						
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Small	<55 (mm)	56-60 (mm)	61-65 (mm)	66-70 (mm)	>70 (mm)	Total
1	Yes	Yes	Yes	Yes	31 - 145	3 - 64	19 - 132	15 - 85	6 - 76	1 - 37	**109 - 368**
2	Yes	Yes	Yes	No	14 - 323	2 - 32	4 - 96	9 - 104	18 - 58	0 - 64	**127 - 462**
3	Yes	Yes	No	No	14 - 215	3 -127	7 - 99	18 - 121	8 - 87	0 - 39	**99 - 383**
4	Yes	No	Yes	Yes	9 - 266	8 -116	54 - 101	36 - 96	16 - 85	0 - 34	**232 - 476**
5	Yes	No	Yes	No	7 - 149	2 -103	1 - 111	11 - 77	7 - 50	0 - 53	**100 - 313**
6	Yes	No	No	No	4 - 240	6 - 73	15 - 127	21 - 91	17 - 62	0 - 95	**137 - 407**
7	No	No	No	No	17 - 196	8 - 146	29 - 146	16 - 87	2 - 55	0 - 65	**124 - 533**
8	No	Yes	No	No	37 - 250	0 - 77	12 - 62	28 - 108	34 - 85	1 - 46	**217 - 413**
9	Hand	No	No	No	10 - 163	2 - 20	7 - 60	13 - 73	24 - 66	2 - 64	**139 - 327**

Table 8a. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean total fruit weight per size class (<55mm to >70mm) per Queen Cox tree, measured on 9 September 2004.**

	Treatment				Fruit weight (kg)						
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Small	<55 (mm)	56-60 (mm)	61-65 (mm)	66-70 (mm)	>70 (mm)	Total
1	Yes	Yes	Yes	Yes	1.4 - 6.9	0.2 - 5.3	1.4-9.8	1.5-7.8	0.7-8.7	0.2-5.5	**8.4-25.7**
2	Yes	Yes	Yes	No	0.7 - 9.9	0.1 - 2.3	0.3-7	0.9-9.5	2.3-6.5	0-11.5	**14-31.6**
3	Yes	Yes	No	No	1.4 - 9.5	0.2 - 5.1	0.6-7	2-11.9	0.9-11.1	0-6.2	**13.5-30.8**
4	Yes	No	Yes	Yes	0.5 - 5.9	0.4 - 5.1	2.8-8.3	4.2-9.5	1.9-10.4	0-4.7	**23.2-30.9**
5	Yes	No	Yes	No	0.5 - 6.2	0.1 - 6.1	0.1-10.7	1.1-7.1	1-5.9	0.-8.5	**13.5-24.1**
6	Yes	No	No	No	0.4 - 9.6	0.3 - 4.7	1.1-11.5	2-9	2.1-7.5	0-15.2	**16.1-29.9**
7	No	No	No	No	0.7 - 9	0.5 - 10	1.5-11.1	1.6-7.5	0.3-6.9	0-10.5	**11-40.2**
8	No	Yes	No	No	0.3 - 9.7	0 - 4.5	1-5.7	3.4-10.1	3.3-10.4	0.1-6.9	**22.2-30.6**
9	Hand	No	No	No	0.6 - 9.5	0.1 - 1.5	0.6-4.3	1.2-7.1	2.8-8	0.3-10	**16.8-28.3**

Table 10a. The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean fruit number per size class (56-65mm and 66+mm) and fruit weight (kg) per Queen Cox tree, measured on 9 September 2004.

	Treatment				Fruit number		Fruit weight	
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	56-65 mm	66+ mm	56-65 mm	66+ mm
1	Yes	Yes	Yes	Yes	43-188	7-93	3.5-15.9	0.9-12.2
2	Yes	Yes	Yes	No	13-200	18-96	1.2-16.5	2.3-15.7
3	Yes	Yes	No	No	25-220	8-126	2.6-19.7	0.9-17.3
4	Yes	No	Yes	Yes	100-172	18-111	8.5-14.8	2.1-14.2
5	Yes	No	Yes	No	13-147	7-80	1.3-15	1-12.3
6	Yes	No	No	No	37-171	17-120	4.6-12.8	2.1-18.4
7	No	No	No	No	25-221	2-120	3.1-21.1	0.3-17.4
8	No	Yes	No	No	20-121	26-122	6.5-15.8	4.5-17.3
9	Hand	No	No	No	70-163	39-116	1.8-10.1	3.1-12.7

Table 12a. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean fruit number per size class (<55mm to >70mm) per Queen Cox tree, measured on 9 September 2004. Small misshapen fruit (attacked by rosy apple aphid) have been proportionally incorporated into each size category.**

	Treatment				Fruit number					
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	<55 (mm)	56-60 (mm)	61-65 (mm)	66-70 (mm)	>70 (mm)	Total
1	Yes	Yes	Yes	Yes	5-98	34-147	21-130	14-101	2-67	**109 - 368**
2	Yes	Yes	Yes	No	2-67	5-135	10-172	30-86	0-73	**127 - 462**
3	Yes	Yes	No	No	4-184	8-116	21-144	12-100	0-70	**99 - 383**
4	Yes	No	Yes	Yes	10-178	48-193	86-110	26-101	0-46	**232 - 476**
5	Yes	No	Yes	No	2-125	1-135	13-110	9-72	0-57	**100 - 313**
6	Yes	No	No	No	8-81	16-141	33-155	34-106	0-128	**137 - 407**
7	No	No	No	No	11-220	26-220	22-97	15-63	0-74	**124 - 533**
8	No	Yes	No	No	0-73	14-114	40-120	40-142	1-56	**217 - 413**
9	Hand	No	No	No	3-19	9-84	17-93	34-114	3-84	**139 - 327**

Table 13a. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean total fruit weight per size class (<55mm to >70mm) per Queen Cox tree, measured on 9 September 2004. Small misshapen fruit (attacked by rosy apple aphid) have been proportionally incorporated into each size category.**

	Treatment				Fruit weight (kg)					
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	<55 (mm)	56-60 (mm)	61-65 (mm)	66-70 (mm)	>70 (mm)	Total yield
1	Yes	Yes	Yes	Yes	0.4-8.2	2.5-10.9	2.1-11.9	1.6-12.1	0.3-10	**9.8-34**
2	Yes	Yes	Yes	No	0.1-4	0.3-9.8	1-16.6	3.8-9.6	0-13.2	**19.1-35.9**
3	Yes	Yes	No	No	0.2-7.4	0.7-8.7	2.3-13.8	1.3-12.7	0-9.7	**14.1-35.9**
4	Yes	No	Yes	Yes	0.5-7.8	3.8-18	7.6-10.8	3-12.3	0-6.3	**23.6-43.5**
5	Yes	No	Yes	No	0.1-7.4	0.1-13	1.3-10.2	1.2-8.2	0-10.9	**14.2-29.3**
6	Yes	No	No	No	0.4-5.2	1.1-12.7	3.3-15.4	2.3-12.8	0-20.4	**16.2-38.4**
7	No	No	No	No	0.7-15.1	2-24.2	2.2-10.8	0.4-7.8	0-11.9	**12.3-50**
8	No	Yes	No	No	0-5.3	1.2-8.9	4.8-12	4.7-12.7	0.1-8.5	**24.8-35.5**
9	Hand	No	No	No	0.1-1.7	0.8-6.1	1.6-8.9	3.9-12.8	0.4-13.2	**19.4-36.5**

Table 14a. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean fruit number per size class (56-65mm and 66+mm) and fruit weight (kg) per Queen Cox tree, measured on 9 September 2004. Small misshapen fruit (attacked by rosy apple aphid) have been proportionally incorporated into size categories for weight and number.**

	Treatment				Number of fruit		Fruit weight	
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	56-65 mm	66+ mm	56-65 mm	66+ mm
1	Yes	Yes	Yes	Yes	60-270	16-168	4.9-22.1	2.1-22.1
2	Yes	Yes	Yes	No	15-292	30-110	1.4-25.3	3.8-18
3	Yes	Yes	No	No	30-246	12-145	3-22	1.3-19.8
4	Yes	No	Yes	Yes	134-286	33-133	11.4-28.8	3.8-16.8
5	Yes	No	Yes	No	14-179	9-116	1.4-18.3	1.2-15.3
6	Yes	No	No	No	48-251	19-161	4.7-21.9	2.3-24.7
7	No	No	No	No	48-288	3-136	4.2-31.9	0.4-19.8
8	No	Yes	No	No	83-223	46-162	2.4-13.9	4.4-25.3
9	Hand	No	No	No	26-170	37-97	7.8-18.7	5.3-21.2

Table 16a. **The effects of pruning during the dormant season (March and April) and concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean flower cluster number per Bramley's Seedling tree, measured on 30 April 2004.**

	Treatment		Number of flower clusters			
	Dormant prune	Dormant PGR	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	19-86	2-84	156-597	**229-684**
2	Yes	Yes	24-97	0-40	168-380	**270-457**
3	Yes	Yes	10-94	1-22	141-379	**152-434**
4	Yes	No	26-234	2-54	188-374	**227-632**
5	Yes	No	37-111	6-30	183-391	**241-528**
6	Yes	No	25-215	3-52	218-412	**246-615**
7	No	No	71-155	2-41	216-445	**289-539**
8	No	Yes	45-144	1-41	193-447	**272-525**
9	Hand	No	19-154	1-43	98-298	**118-376**

Table 18a. **The effects of pruning during the dormant season (March and April), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean fruit number per flower position (terminal, axillary and spur) per Bramley's Seedling tree, measured on 12 July 2004.**

	Treatment				Number of fruit			
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Terminal position	Axillary position	Spur position	Total
1	Yes	Yes	Yes	Yes	13-33	3-21	48-126	**77-146**
2	Yes	Yes	Yes	No	14-39	0-19	56-137	**79-182**
3	Yes	Yes	No	No	11-32	3-21	53-99	**75-129**
4	Yes	No	Yes	Yes	11-48	4-12	61-76	**80-131**
5	Yes	No	Yes	No	14-39	1-16	48-123	**72-147**
6	Yes	No	No	No	17-52	3-22	58-107	**79-167**
7	No	No	No	No	17-46	2-18	71-128	**124-165**
8	No	Yes	No	No	4-59	8-20	55-109	**85-188**
9	Hand	No	No	No	6-57	1-14	33-136	**43-160**

Table 20a. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in percentage of fruit number per size class (<65mm to +101mm) per Bramley's Seedling tree, measured on 9 September 2004.**

	Treatment				Percentage of number of fruit in each size class								
	Dormant prune?	Dormant PGR?	Petal fall prune?	Petal fall PGR?	<65 mm	66-70 mm	71-75 mm	76-80 mm	81-85 mm	86-90 mm	91-95 mm	96-100 mm	101+ mm
1	Yes	Yes	Yes	Yes	0-4	0-12	0-16	4-64	8-28	4-44	0-20	0-12	0-12
2	Yes	Yes	Yes	No	0-4	0-4	0-16	12-24	8-32	20-36	4-24	0-12	0-4
3	Yes	Yes	No	No	0-12	0-16	0-10	8-28	14-36	20-40	4-24	0-12	0-5
4	Yes	No	Yes	Yes	0-40	0-12	4-16	8-24	8-36	16-32	0-28	0-16	0-4
5	Yes	No	Yes	No	0-4	0-8	4-20	12-32	12-28	12-40	8-20	0-8	0-0
6	Yes	No	No	No	0-12	0-20	4-16	0-36	4-32	4-52	0-20	0-8	0-8
7	No	No	No	No	0-4	0-4	0-8	8-28	16-32	8-44	4-44	0-8	0-4
8	No	Yes	No	No	0-4	0-8	4-12	4-24	16-32	28-40	0-20	0-12	0-4
9	Hand	No	No	No	0-8	0-12	4-28	4-28	8-44	17-38	8-36	0-8	0-8

Table 22a. **The effects of pruning during the dormant season (March), and at petal fall, with concurrent application of the plant growth regulator 'Cultar', to pruning wounds, on the variation in mean fruit weight in each size class (<80mm, 81-100mm and 101+mm diameter) expressed as a percentage of the total weight (kg) per Bramley's Seedling tree, measured on 9 September 2004.**

	Treatment				Percentage number of fruit in each size class		
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	<80mm	81-100mm	101mm+
1	Yes	Yes	Yes	Yes	4-80	20-92	0-12
2	Yes	Yes	Yes	No	12-44	56-88	0-4
3	Yes	Yes	No	No	12-44	56-88	0-5
4	Yes	No	Yes	Yes	20-76	24-76	0-4
5	Yes	No	Yes	No	16-52	48-76	0-0
6	Yes	No	No	No	16-80	20-80	0-8
7	No	No	No	No	8-40	72-92	0-4
8	No	Yes	No	No	16-36	64-84	0-4
9	Hand	No	No	No	4-44	56-89	0-8

Table 23a. **The variation in number of new shoots (>5cm), average new shoot length, and total new shoot growth occurring in the growing season of 2004 for Queen Cox per tree. Measurements were made in January 2005.**

	Treatment						
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Number of new shoots	Average shoot length (cm)	Total shoot growth (m)
1	Yes	Yes	Yes	Yes	56-130	17-22	**9.7-32.8**
2	Yes	Yes	Yes	No	48-266	17-33	**9.0-87.5**
3	Yes	Yes	No	No	30-204	19-32	**5.8-64.8**
4	Yes	No	Yes	Yes	96-145	22-26	**21.0-33.5**
5	Yes	No	Yes	No	56-195	15-34	**8.5-65.5**
6	Yes	No	No	No	43-224	16-26	**7.6-72.1**
7	No	No	No	No	20-161	13-24	**3.0-39.2**
8	No	Yes	No	No	53-123	15-25	**8.1-26.0**
9	Hand	No	No	No	45-120	22-38	**10.1-40.5**

Table 25a. The variation in number of new shoots (>5cm), average new shoot length, and total new shoot growth occurring in the growing season of 2004 for Bramley's Seedling per tree. Measurements were made in January 2005.

	Treatment						
	Dormant prune	Dormant PGR	Petal fall prune	Petal fall PGR	Number of new shoots	Average shoot length (cm)	Total shoot growth (m)
1	Yes	Yes	Yes	Yes	124-275	25-38	**31.4-90.6**
2	Yes	Yes	Yes	No	109-312	28-40	**30.3-86.8**
3	Yes	Yes	No	No	184-285	32-42	**67.3-94.3**
4	Yes	No	Yes	Yes	157-298	27-54	**48.3-112.9**
5	Yes	No	Yes	No	148-258	28-42	**50-96.7**
6	Yes	No	No	No	106-321	15-46	**16.4-106.4**
7	No	No	No	No	146-321	27-43	**39-138.3**
8	No	Yes	No	No	215-343	32-38	**69.3-131.7**
9	Hand	No	No	No	132-217	21-47	**38.8-96.6**

Appendix IV

Queen Cox experimental orchard plan used at EMR

				Tree number
CW120			G	36
			G	35
			G	34
			8	33
			6	32
	Block	**1**	9	31
			5	30
			1	29
			4	28
			3	27
			7	26
			2	25
			G	24
			4	23
			1	22
			8	21
	Block	**2**	3	20
			9	19
			2	18
			7	17
			5	16
			6	15
			G	14
			8	13
			7	12
			6	11
			9	10
	Block	**3**	1	9
			3	8
			4	7
			5	6
			2	5
			G	4
			G	3
			G	2
			G	1
CW121			G	41
			3	40
			2	39
			1	38
			4	37
	Block	**4**	5	36
			9	35
			8	34
			6	33
			7	32
			G	31
			1	30
			6	29
			2	28
			8	27
	Block	**5**	7	26
			4	25
			3	24
			9	23
			5	22
			G	21
			9	20
			2	19
			8	18
			3	17
	Block	**6**	1	16
			4	15
			7	14
			5	13
			6	12
			G	11
			5	10
			7	9
			8	8
			1	7
	Block	**7**	3	6
			2	5
			6	4
			4	3
			9	2
			G	1
			Row 6	**GREAT EAST**

Code Treat	Dormant season prune	Dormant season PRG	Petal fall prune	Petal fall PRG
1	plus	plus	plus	plus
2	plus	plus	plus	minus
3	plus	plus	minus	minus
4	plus	minus	plus	plus
5	plus	minus	plus	minus
6	plus	minus	minus	minus
7	minus	minus		
8	minus	plus		
9	Hand prun			

Trees taped -

BLUE (dormant pruning - treatments 1-6)

RED (PGR - treatments 1-3 and 8)

GREEN (hand pruning - treatment 9)

Appendix V

Bramley's Seedling experimental orchard plan used at Figgis' Farm

TF153
Bramley

Brick Close, Wey Street Farm

	North Row 8	Tree number			North Row 7	Tree number
	G	55				
	P	54				
	G	53				
	G	52				
	G	51				
	P	50			G	50
	G	49			G	49
	3	48			G	48
	G	47			P	47
	2	46			G	46
	1	45			G	45
	4	44			G	44
	P	43			G	43
4	5	42			G	42
	9	41			G	41
	8	40			G	40
	6	39			P	39
	7	38			G	38
	G	37			G	37
	1	36			8	36
	6	35			6	35
	P	34			9	34
	2	33			5	33
	8	32	**Block**	**1**	1	32
5	7	31			P	31
	4	30			4	30
	3	29			3	29
	9	28			7	28
	5	27			2	27
	P	26			G	26
	G	25			4	25
	9	24			1	24
	2	23			P	23
	8	22			8	22
	3	21	**Block**	**2**	3	21
6	1	20			9	20
	4	19			2	19
	P	18			7	18
	7	17			5	17
	5	16			6	16
	6	15			P	15
	G	14			G	14
	5	13			8	13
	7	12			7	12
	8	11			6	11
	P	10			9	10
	1	9	**Block**	**3**	1	9
7	3	8			3	8
	2	7			P	7
	6	6			4	6
	4	5			5	5
	9	4			2	4
	P	3			G	3
	G	2			P	2
	G	1			G	1
	South				**South**	

Code Treat	Dormant season prune	Dormant season PRG	Petal fall prune	Petal fall PRG
1	plus	plus	plus	plus
2	plus	plus	plus	minus
3	plus	plus	minus	minus
4	plus	minus	plus	plus
5	plus	minus	plus	minus
6	plus	minus	minus	minus
7	minus	minus		
8	minus	plus		
9	Hand prune			

Trees taped for 24/03/04 -

BLUE (dormant pruning - treatments 1-6)
RED (PGR - treatments 1-3 and 8)
GREEN (hand pruning - treatment 9)
YELLOW (pollinators)
YELLOW/GREEN (guard trees)