Overcropping Gala tree

Thinning flowers and fruitlets

Introduction

Apple trees frequently set and retain excessive numbers of fruits in relation to tree size and leaf area. The result of this is the production of fruits at harvest which are smaller than required by the markets and which often show poor storage potential.

- Reduce the fruit numbers on the trees so that only those that can be sized adequately are retained through to harvest.
- Remember that on a small tree it is better to have 80 apples which average 68 mm in diameter than 120 apples averaging 60 mm.
- Recent research shows that fruits from thinned trees have higher concentrations of polyphenols which are important to human health and nutrition.

- Larger fruits are:
  - Easier and cheaper to pick
  - Cheaper to grade

This essential crop load adjustment can be achieved using several strategies, which are discussed in the sections below.

Optimum levels of fruit set for UK apple varieties

Introduction

The best way to assess the optimum fruit set is to use at least three years historical cropping and grading information to calculate the average number of fruits per kilogram and from the yield data then calculate the average numbers of fruits per tree.

- By adding a number for fruit dropped at harvest (approximately 5%) the number of fruits left after thinning can be arrived at.
- In modern intensive orchards on M9 there is rarely a significant June drop but this will have to be taken into account on old or vigorous Cox orchards with a history of variable cropping.
- Thin to specified numbers of fruits per tree.
- Thin to specified numbers of fruits per flower cluster.

Summary of best practices for achieving optimum fruit numbers

Deciding whether to reduce the crop load (by thinning or other methods)

It is important to maximise yields of apples in the grades most desired by the markets in order to sustain reasonable profitability.

- Maximising fruit set and total yields is rarely the best strategy, as this usually results in the production of too many fruits of small size and poor storage potential.
- In contrast, to maximise the yield per tree of top quality fruits it is important not to thin trees more than is necessary.
- Decisions on whether to thin or not are, therefore, not always easy to make.

For some crops, decision support models are being developed to aid fruit growers in making these decisions. One example is a model focused on crop loading of kiwi fruit vines developed in New Zealand (Mills and Atkins, 1992).

- No sophisticated crop loading models exist currently for apples grown in the UK and the grower must use experience of the orchard, knowledge of weather conditions and, often, natural intuition in making decisions on the need to thin.

The main factors which determine the need or not to thin an orchard are:

- The variety
- The rootstock
- The market requirements for the fruits
- The current season's weather
- The condition of the tree

The variety

Small-fruited varieties, such as Gala and Cox and their various clones, are more likely to require regular thinning than larger fruited varieties such as Jonagold, Braeburn or Bramley.

- If the small-fruited variety is also prone to set heavily, as Gala is, then the need for seasonal and early thinning becomes even more acute.

The rootstock

Trees grown on very dwarfing rootstocks, such as M27, need thinning in most years if adequate fruit size is to be achieved. This is particularly important when growing varieties such as Gala or Cox on this rootstock.

Average fruit size on the popular rootstock M9 (EMLA, Rajam 1, Rajam 2, etc.) is generally better than on most other rootstocks and thinning severity will not need to be as great as for trees on M27.
- However, where M9 is planted on soils of lower than average fertility or where temporary drought conditions prevail the shallow roots of trees on M9 will make them vulnerable to producing small fruit sizes unless irrigation and/or judicious thinning is carried out.

Trees on the rootstocks MM106 and P22 are also prone to overset and small fruit size on many sites and careful attention should be paid to adequate thinning.

The market requirements for the fruit

Most dessert apple varieties are grown for the fresh markets. Multiple retailers will now take a range of sizes and colour to satisfy their demand for consumer choice.

Where fruits are marketed through alternative channels (farmers’ markets, farm shops etc.) different standards of background colour and fruit firmness may be acceptable.

- Care must be taken not to over-thin large-fruited varieties such as Jonagold, or fruit too large for the UK consumer markets may be produced.
- Bramley fruit, especially those grown for the fresh market, are usually required to be in the range 90-110mm. This requires careful crop load management and pruning.
- Slightly smaller fruits and hence higher crop loads can be tolerated where the Bramley are focused on the processing markets.

The current season’s weather

This is often the most important factor to take account of when deciding whether to thin or not.

- Frost or cold, windy or wet weather during the flowering period usually equates with poor fruit set.
- When these unfavourable conditions prevail, growers are, understandably, reluctant to contemplate early (blossom) thinning.
- In these situations decisions on thinning are usually delayed until after fruit set, when the potential crop load can be assessed.
- Whilst this decision was sound in the past, as later thinning with Thinsec (carbaryl) was always an option, the withdrawal of carbaryl for use as a thinning agent means that until BA is approved, hand thinning will remain the only option.
- When deciding to blossom thin will always give the best assurance of adequate fruit set should a frost occur in late bloom, it will be associated with a high cost for hand thinning if fruit set turns out to be bigger than required.

Temperatures during the cell division period (full bloom through to six weeks later) will influence fruit size.

- Where this period experiences higher than average temperatures, fruit size is more likely to be adequate.
- The exact relationship is not fully understood and fruit numbers per tree will override the temperature effect.

The condition of the tree

Trees in healthy condition with minimal shoot growth, dark leaves and many fruitlets that are clearly set should be thinned because such trees are likely to retain excessive numbers of fruitlets through to harvest.

- However, such healthy trees are also able to support and size up more fruits than less healthy trees.

Trees in less healthy condition or those lacking nitrogen, as often found in organic plantings, also need thinning.

- Often this needs to be more severe thinning, as the weakened trees are able to size up fewer fruits per unit tree size than healthy or well fertilised trees.

Thinning to specific numbers of fruits per tree

Mature and well-managed apple trees develop approximately similar numbers of spur and extension leaves in each season. These leaves are vital for producing, by photosynthesis, the food stuffs (sugars, carbohydrates) that power the growth of the fruits.

It is reasonable to suggest, therefore, that optimum fruit numbers that can be developed to full size by the tree, are related closely to:

- Tree size, especially canopy volume, and
- Light interception.

If light interception and temperatures were similar in most seasons, then the numbers of fruits that the mature tree could grow to full size would also be similar in most seasons.

- Climatic conditions differ slightly in most seasons, however, and some adjustments to optimum fruit numbers need to be made in the light of these seasonal variations.
- Thinning to ideal numbers of fruit per tree, is more logical and gives less variable effects than the often used strategy of thinning to specific numbers of fruit (1 or 2) per floral bud.

Trials conducted in France on six-year-old Royal Gala/M9 trees at a spacing of 4 x 2 m showed that cropping loads of 120, 180 and 240 fruits per tree were equivalent to 5, 7 and 9 fruits per square centimetre of trunk cross sectional area.

- In these trials, in which the crop loads were established by thinning 20 days and 50 days after flowering, the two lighter crop loads produced 90% of their fruits in the top grades.
- The highest crop loading produced only 70% in the top grades.
- Large differences in ripening were noted with 58% or fruits ready for harvest at the first picking date on the lightest cropping trees, but only 27% on the heaviest cropping trees.

Thinning to specific numbers of fruits per blossom cluster

The traditional practice in fruit thinning is to thin to either one or two fruits per flower cluster.

- On sites which regularly produce heavy crops of smallish fruits, thinning to single fruits per cluster is usually recommended.
- On more fertile sites, or with larger fruited varieties, thinning to two fruits per cluster is often preferred.
- Usually, this cluster thinning is combined with removal of all or most fruitlets on axillary wood.

Whilst this strategy of thinning is easy to explain to farm staff, it is rarely the best one for orchards.

- The abundance of flowering in trees varies from year to year and thinning to specific numbers of fruits/cluster may, therefore, result in very different crop loads per tree.
Also, work in New Zealand has shown that it is better to leave two or even three fruits per cluster on 'strong' clusters and completely remove all fruits from other 'weaker' clusters. Similarly, strong floral buds on the one-year-old wood of varieties such as Gala can, on fertile sites with good tree growth, produce good fruit size and quality. Ideally, growers should acquire an intuitive understanding of the type and size of crop which trees in particular orchards are capable of carrying and then thin accordingly. Unfortunately, this intuitive understanding is difficult to pass on to the casual labour often used for fruit thinning.

Where possible growers should aim to thin trees to specified fruit numbers/tree (see above) rather than to specific numbers of fruits/flower cluster.

**Optimum fruit numbers needed per tree in UK orchards**

Trials and observations conducted by FAST in the UK have demonstrated the value of using thinning guidelines based on target numbers of fruits per tree at harvest.

- These target fruit numbers are adjusted to take account of the tree spacings within the rows or between rows in multi-row beds.
- Use the table below as a guide to fruit numbers per tree
- Better still using accurate grading records calculate the actual numbers per tree over the last three seasons and relate these to optimum yield and fruit size expectations.

<table>
<thead>
<tr>
<th>Tree spacing</th>
<th>Target number of fruits/tree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cox &amp; Discovery</td>
</tr>
<tr>
<td>1-1.25m</td>
<td>80</td>
</tr>
<tr>
<td>1.5m</td>
<td>95</td>
</tr>
<tr>
<td>1.75-2m</td>
<td>110</td>
</tr>
<tr>
<td>2.5m</td>
<td>215</td>
</tr>
<tr>
<td>3.5-4.0m</td>
<td>420</td>
</tr>
</tbody>
</table>

The above numbers of fruits are those required at the time of harvest and, if thinning is carried out prior to 'June Drop', extra fruit numbers will need to be left on the trees to compensate for this.

- For early thinning, approximately 10% to 20% more fruitlets should be left on the trees than shown in the above table.

**Modern weight/size grading equipment will provide accurate weights of fruits and therefore fruits per kg for each size band. Where these are not available use the figures below as a guide**

<table>
<thead>
<tr>
<th>Dessert Fruit</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>Kg</td>
<td>Size</td>
</tr>
<tr>
<td>&lt;55 mm</td>
<td>0.06</td>
<td>&lt;70 mm</td>
</tr>
<tr>
<td>55-60 mm</td>
<td>0.07</td>
<td>70-80 mm</td>
</tr>
<tr>
<td>60-65 mm</td>
<td>0.08</td>
<td>80-90 mm</td>
</tr>
<tr>
<td>65-70 mm</td>
<td>0.10</td>
<td>90-100 mm</td>
</tr>
</tbody>
</table>
Methods of reducing crop load including flower/fruitlet thinning

First decide whether there is a need to thin the apple orchard and to what level and then determine which method of thinning is the most appropriate.

There are several possible strategies to optimise the crop loads on apple trees. The potential numbers of fruits can be reduced by:

- The removal of sites of floral bud development in winter pruning
- Flower thinning and/or
- Fruitlet thinning.

It is important to decide which of these methods are appropriate.

Do I need to thin and which method should I use?

Flower (blossom) thinning

If current guidelines on rates and timings are observed, over thinning with a chemical blossom thinner is unlikely. The aim is to reduce the cost of hand thinning.

Before deciding on blossom thinning it is important to ask:

- Does historical data show consistently that thinning is necessary?
- Are the flower cluster numbers twice as high (or more) than necessary for a good set?
- Has there been little or no frost damage and none forecast?

If the answer is yes to the above it is definitely appropriate to consider blossom thinning.

Fruitlet thinning

When contemplating the need for thinning of fruitlets it is vital to ask:

- Are trees compact in growth?
- Are leaves small and dark?
- Are fruitlet numbers double or more than required?
- Are fruitlets clearly visible above foliage?

If the answer is yes to the above it is definitely appropriate to consider a fruitlet thinning treatment.

Hand thinning

When contemplating the need for hand thinning of fruitlets, it is vital to follow the following guidelines:

- Check fruit numbers on at least 10 representative trees in each orchard.
- Estimate whether fruit numbers more than 120% of those required at harvest?
- If thinning is warranted, hand thin to optimum fruitlet numbers (before fruitlets reach 25 mm in diameter).
- Remove small and shaded fruitlets and those on weak wood.
- Where fruitlet numbers are between 100% and 120% of optimum, wait and reassess 2–3 weeks later. If necessary, thin at this later stage removing poor quality fruit.

Removal of sites of floral bud development in winter pruning

Winter pruning can reduce the need for flower or fruitlet thinning on trees that regularly set too many fruits

- On trees which are making excessive numbers of flowers, too many of which set resulting in poor fruit size, spur reduction should be carried out as part of winter pruning.
- On trees where excessive flowering is accompanied by minimal new shoot growth, some renewal pruning of branches should be carried out to restore a better balance between shoot growth and flowering.
- This usually entails heading back some of the branches quite severely.

Flower (blossom) thinning

- Flower thinning involves the removal of a proportion of the flowers (hand or mechanical methods of flower thinning) or alternatively treating flowers in some way to prevent them setting fruits (chemical methods of flower thinning).

Mechanical methods of flower thinning have been developed and have proved successful on close planted orchards on the continent. These mainly involve the use of revolving plastic filaments similar to that used in a strimmer.

Hand thinning of apple flowers

- Hand thinning of flowers has the advantages that it is environmentally sensitive (uses no chemicals) and allows competition between developing fruitlets to be reduced at the earliest opportunity.
However, hand thinning of flower clusters is rarely if ever carried out in mature commercial orchards. It is too labour intensive and hence too expensive.

Hand removal of flower clusters on newly planted trees may be appropriate in the first one or two seasons.

Chemical methods of thinning apple flowers

Most chemicals that have been tested and found effective in preventing apple flowers setting fruits work by desiccating the flower organs and preventing pollination and/or fertilisation (fruit set).

There are a number of chemicals that work in this way but the only one currently available to UK growers is the nutrient ammonium thiosulphate (ATS)

**Ammonium thiosulphate (ATS)**

The foliar nutrient ATS has a very useful side effect as a blossom thinner on apples and other crops.

- If applied at flowering time, ATS works by desiccating and, therefore, damaging the stigmas and styles of apple flowers, so preventing them setting fruits.

When using ATS as a *blossom thinner* on apples it is important to consider the best timings for the sprays, the ideal weather conditions, the optimum spray concentrations and any variations in treatment associated with different apple scion varieties.

**Spray timings when using ATS**

- Thinning using ATS is most efficient if the sprays are applied between 20% and 50% full bloom.
- Flowers which are at balloon stage through to those that have been open for 2 days are the most sensitive to the sprays.
- Although the petals of flowers at the pink bud stage are damaged by ATS sprays, the flowers still remain capable of setting fruits.
- Flowers that have been open for more than two days and have been pollinated by bees will often still set fruits, although damaged by the ATS sprays.
- In seasons when flowering is concentrated over just a few days, then a single treatment with ATS will often be sufficient to thin the trees effectively.
- In years when the blossoming period is extended two sprays may be required; the first when 25% of the blossoms have opened and a second when most of the spur flowers have opened.
- With varieties that are prone to set large numbers of fruits on one-year-old wood (axillary blossoms) growers often endeavour to selectively prevent this fruit set using sprays of ATS applied after full bloom.
- Axillary blossoms, which often give rise to smaller than average fruits at harvest, flower several days after spur blossoms and to thin them ATS sprays must be delayed until early petal fall on spur blossoms.
- Care must be taken with this late treatment; however, if damage to fruitlets set earlier is to be avoided.

**The ideal weather conditions**

- As temperatures increase above 15°C, the efficiency of thinning when using ATS is increased.
- Slow drying conditions (high humidities) improve thinning slightly, but may also cause phytotoxicity on the spur leaves.
- Spraying high concentrations of ATS in slow drying conditions is not recommended on account of the potential problems of phytotoxicity to the spur leaves.
- Spur leaves are essential to the early growth of the persisting fruitlets.

**Spray concentrations and volumes**

Throughout the world the most effective ATS concentrations for thinning apples have ranged from 0.5% to 2.0%.

- Throughout the world the most effective ATS concentrations for thinning apples have ranged from 0.5% to 2.0%.
- In the UK concentrations of 1.0% or 1.5% have generally proved most effective in the trials conducted.
- The required concentration and also spray volume for effective flower thinning is influenced by both the temperature and the relative humidity.
- Research in Canada has indicated that when sprays of ATS are applied at low volumes the spray concentration needs to be increased, in comparison with sprays applied at high volumes.
- Research in Poland indicates that sprays of ATS applied at low volumes (at appropriate concentrations) are more effective than sprays applied at high volumes.

The table below gives some guidance on concentrations and spray volumes as influenced by the temperatures and humidities at the time of spraying

**Slow Drying**

<table>
<thead>
<tr>
<th>Relative Humidity (%)</th>
<th>Temperature °C</th>
<th>ATS %</th>
<th>Litres/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10-15</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>15-20</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>20+</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**The table below gives some guidance on concentrations and spray volumes as influenced by the temperatures and humidities at the time of spraying**
**Quick Drying**

- It may be necessary to increase the concentrations of ATS by 0.5% on very heavy setting varieties or alternatively, apply a second spray.
- Most proprietary brands of ATS contain 85% or more of ATS with smaller amounts of impurities.
- Trials at East Malling have shown that two of the ATS brands available in the UK, Thiosul and F3000, are approximately similar in their thinning efficacy and differ very little in the small amount of phytotoxicity induced on spur leaves.
- The brand ‘Blossom Plus’ is similar in its efficacy.
- 1.176 litres of products containing 85% active ingredient ATS in 100 litres of water will give a spray concentration of 1.0%.

The tables below show amounts of ‘Blossom Plus’ required to achieve different ATS concentrations in different volumes of water

<table>
<thead>
<tr>
<th>Water vol. GPA</th>
<th>Pints of ‘Blossom Plus’</th>
<th>Water vol. L/ha</th>
<th>Litres of ‘Blossom Plus’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ATS concentration %</td>
<td></td>
<td>ATS concentration %</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>20</td>
<td>0.8</td>
<td>1.6</td>
<td>2.4</td>
</tr>
<tr>
<td>40</td>
<td>1.6</td>
<td>3.2</td>
<td>4.8</td>
</tr>
<tr>
<td>60</td>
<td>2.4</td>
<td>4.8</td>
<td>7.2</td>
</tr>
<tr>
<td>80</td>
<td>3.2</td>
<td>6.4</td>
<td>9.6</td>
</tr>
<tr>
<td>100</td>
<td>4.0</td>
<td>8.0</td>
<td>12.0</td>
</tr>
</tbody>
</table>

**Use of adjuvants**

- A low rate of a non-ionic wetter will improve the action of ATS and can be used except in very slow drying conditions.
- Do not tank mix ATS with any other spray material or apply within 2 days of applying other sprays, or excess leaf damage may occur.

Variations associated with specific varieties

Varieties differ slightly in terms of their thinning requirements and hence in the ideal ATS treatment required for optimum thinning; brief recommendations are presented below:

- **Alkmene (Early Windsor/Ceeval)** One application of ATS at 1.0-1.5% at full bloom is sufficient and no adjuvant is usually necessary.
- **Braeburn** Braeburn tends to have a very concentrated blossom period and ATS can thin a greater proportion of flowers in one spray than on other varieties. For this reason it should be used with caution especially on young trees.
- **Bramley** Two applications of 1.5-2.0% ATS, the first at full bloom on two-year-old wood and the second approximately 7 days later.
- **Cox** One application of ATS at 1.0-1.5% just after bloom on two-year-old wood. Do not include any adjuvant unless blossoming is very profuse.
- **Discovery** One application of ATS at 1.0-1.5% just after bloom on two-year-old wood. Do not include any adjuvant unless blossoming is very profuse.
- **Egremont Russet** Two applications of 1.5% ATS are usually necessary. The first is applied at 80%-90% full bloom on two-year-old wood and the second approximately 7 days later. Only include adjuvant if profuse amounts of bloom are present and fruit size is a known problem associated with the orchard.
- **Gala** Two applications of ATS at 1.0-1.5%; the first timed at 80% full bloom on the two-year-old wood and the second approximately 7 days later. The second spray is aimed to target axillary blossoms on one-year-old wood.
- **Golden Delicious** Trials in Europe have shown that sprays of 1% to 2% (depending upon blossom abundance and season) are effective in thinning this variety.
- **Jonagored** One application of ATS at 1.0-1.5% at full bloom is sufficient and no adjuvant is usually necessary. Only apply to Jonagored if the orchard has a history of oversetting with small fruit and poor tree growth.
- **Spartan** Two applications of ATS at 1.0-1.5% with the first timed at full bloom on two-year-old wood and the second approximately 7 days later. The second application should be omitted if weather conditions during bloom are not favourable for good fruit set.
Recent evidence from Norway indicates that sprays of 1% ATS are effective in thinning this variety. Worcester Pearmain Two applications of ATS at 1.0-1.5% with the first timed at full bloom on two-year-old wood and the second approximately 7 days later. The second application should be omitted if weather conditions during bloom are not favourable for good fruit set.

Other chemicals tested as flower thinners for apples

Other blossom thinners that have shown promise in trials both in the UK and abroad include Ammothin, common salt (sodium chloride), Endothallic acid, Ethephon, Lime sulphur, Petaronic acid, Urea, Vinegar, Within and Zinc.

Lime sulphur

Lime sulphur was used many years ago as a thinner for Victoria plum. More recently, organic growers in parts of continental Europe have begun to show renewed interest in the product as a thinner for apples.

- Recent trials conducted in the Netherlands indicate that lime sulphur at 4% applied at full bloom can provide useful thinning of the variety Elstar.
- Lime sulphur is not currently approved for use as a flower thinner in the UK.

Urea

Sprays of 3-4% urea have occasionally produced good results when applied at full bloom in German and Danish trials.

- However, the product appears to thin only when it also causes significant damage to the spur leaves.
- Such damage will probably have negative effects on fruit development and calcium uptake into the persisting fruitlets.
- Urea is not approved for use as a flower thinner on apples in the UK.

Fruitlet thinning

In the absence of suitable approved chemicals for thinning fruitlets on apple trees they can only be thinned by hand. This is a very expensive procedure and, with pruning and harvesting, represents one of the major costs in apple production.

- Attempts have been made to thin fruitlets of some crops (e.g. plums) using mechanical aids, but little or no work has focused on this strategy, which relies on tree shaking or combing devices, for apple.
- Fruitlet drop may also be induced using other techniques. One of these, recently tested in the USA, is to induce thinning by shading trees.

Hand thinning

Hand thinning is the best way to achieve the correct crop load and ensures that the largest and best shaped fruits are retained. It also allows the best fruitlet distribution on the tree to be established by allowing fruits in poor positions on the branches or spurs to be removed.

- Even when hand chemical thinning has been carried out, growers should double check the fruit number and hand thin down to the correct crop load per tree.

**Procedures for hand thinning:**

Check the fruit numbers on a small sample of trees and compare with target numbers.

Calculate how many fruits per cluster or per foot of branch length need to remain.

Decide on a simple set of rules for the fruit thinners, e.g:

- Remove all fruits under branches.
- Remove all fruits on one-year-old wood.
- Leave one (or occasionally 2) fruit per cluster.
- Leave fruits to be spaced 10 cm (4 inches) apart.
- On short-stalked varieties (Cox, Discovery, Egremont Russet and Bramley) remove the ‘king’ fruit as this may be misshapen. Leave the next largest lateral fruit in the cluster.
- On long-stalked varieties (Gala and Jonagored) the king fruit is retained as it is the largest and is not misshapen.
- Check the crop load by counting or by using special binoculars provided by advisory specialists. This aid to assessing crop load has proved quick and very reliable.
- Begin thinning as soon as possible as this maximises the benefits to fruit size and texture.

**Timing of hand thinning**

In a research trial conducted at East Malling in 1997, semi-mature trees of Royal Gala on M.9 rootstock were thinned to single fruits per cluster at different timings and the effects on yields and grade outs recorded. The table below shows some of the results:

Effects of different timings of hand thinning Royal Gala trees in 1997

<table>
<thead>
<tr>
<th>Treatment timing of hand thinning</th>
<th>No. fruits/tree</th>
<th>Weight of fruit harvested/tree (kg)</th>
<th>Total</th>
<th>&gt;65 mm diameter</th>
<th>&gt;70 mm diameter</th>
<th>% of total 65 mm diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (control)</td>
<td>235</td>
<td></td>
<td>18.6</td>
<td>1.4</td>
<td>0.1</td>
<td>8</td>
</tr>
<tr>
<td>Stage</td>
<td>Value 1</td>
<td>Value 2</td>
<td>Value 3</td>
<td>Value 4</td>
<td>Value 5</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>Full bloom</td>
<td>52</td>
<td>7.8</td>
<td>6.1</td>
<td>2.6</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>Late initial set</td>
<td>80</td>
<td>10.9</td>
<td>8.0</td>
<td>4.4</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>12 mm diameter</td>
<td>100</td>
<td>12.6</td>
<td>5.9</td>
<td>2.7</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>18 mm diameter</td>
<td>84</td>
<td>9.5</td>
<td>2.8</td>
<td>0.2</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>24 mm diameter</td>
<td>83</td>
<td>9.1</td>
<td>3.3</td>
<td>0.8</td>
<td>36</td>
<td></td>
</tr>
</tbody>
</table>

- Trial results show that thinning at or before the 12 mm fruitlet diameter stage is essential.
- Thinning Gala at the time of initial set is particularly beneficial.
- Very early thinning of Cox may, however, result in some problems in storage.

**Chemical thinning of fruitlets**
- Currently there are no approved products for thinning of fruitlets in the UK.
- Trials with benzyladenine (BA) appear promising and it is hoped that a registration for this may be approved in 2010 or 2011.
- Other chemicals trialled for thinning fruitlets include NAA/NAD and ethephon.

**Combined flower and fruitlet thinning treatments**
Trials and grower experience have shown the benefits of combining flower and fruitlet thinning treatments for maximum thinning effect.
- Consider supplementing any blossom thinning achieved using ATS with supplementary hand thinning at the 12 mm fruitlet diameter stage.
- Recently promising results have been achieved using combinations of ATS for blossom thinning and BA for fruitlet thinning.
- However, BA is not currently approved for use as a fruitlet thinner in the UK.

**The physiology of flower and fruitlet drop in apples**

**The natural abscission (drop) of flowers and fruits**
Fruitlets were traditionally thought to drop off in response to the death of their seeds (embryos) and the cessation of the supply of auxins from the live seeds across the abscission zone in the fruit stalk.
- Although embryo death possibly explains a significant proportion of natural fruitlet abscission, it does not explain it all.
- Fallen fruitlets can often be found which have live plump seeds within them.
- Also, research has failed to explain conclusively the causes of the embryo abortion itself.

**Hormones occurring naturally within the tree that are associated with flower and fruitlet abscission**
- Several natural plant hormones have been implicated in the tree processes leading to flower and/or fruitlet abscission (drop), particularly auxins and ethylene.

**Application of plant growth regulators to induce flower and fruitlet abscission**
- Various chemicals have been shown to have thinning action when sprayed onto apple trees including, auxins, carbaryl, ethylene releasing chemicals, photosynthesis inhibiting chemicals and cytokinins (benzyl adenine – BA).
- Recent studies have shown that jasmonic acid and n-propyl dihydrojasmonate (PDJ) may have potential as a fruitlet thinner in certain fruit crops (Fujisawa et al., 1997).

**Hand thinning of apple flowers**
Hand thinning of flower clusters is rarely ever carried out in mature commercial orchards. Hand thinning is too labour intensive and hence too expensive.

However, experiments conducted in Germany (Link, 1998) have shown the clear benefits of early hand thinning. Experiments conducted in Switzerland on Elstar trees, which were exhibiting pronounced biennial bearing, also showed the advantages of hand thinning of blossoms (Bertschinger et al.,).
- The work demonstrated that biennial bearing of Elstar could best be avoided by removal of 2/3 of the flower clusters on the entire tree in the first year of treatment coupled with some further fruitlet thinning (hand or use of NAA) after June Drop in subsequent years.
- Also effective, was removal of all the flower clusters from half the tree in the first year of treatment, again coupled with subsequent hand thinning of fruitlets.
- This latter option is best for organic Elstar production, as it involves no use of chemical thinners.
- Approximately 8 to 10 minutes were needed to remove all the clusters on 50% of a tree (250 hours/ha if 1500 trees/ha) in the first year of treatments.
- The subsequent treatments took on average 3 minutes per tree.
- The fruits from the trees on which clusters were removed from 50% of the tree canopy proved to be the firmest.
The biennial bearing variety Boskoop also benefits from very early hand thinning in the 'on' year.

- For good return bloom in the subsequent season flower thinning had to be completed in the first two weeks following flowering (Tromp, 2000).

Hand thinning of blossoms is occasionally practised on newly planted trees so as to prevent fruit set and encourage shoot growth to fill the allotted canopy space.

- Hand thinning of flowers has the advantages that it is environmentally sensitive (uses no chemicals) and allows competition between developing fruitlets to be reduced at the earliest opportunity.
- However, hand thinning of flower clusters is rarely if ever carried out in mature commercial orchards. It is too labour intensive and hence too expensive.

### Mechanical thinning of flowers

In recent years machines for mechanical thinning of apple flowers have been developed in Germany, Switzerland and the USA.

- The crudest types of machine use a series of knotted ropes, which are dragged through the trees to knock off a proportion of the flowers.
- The ropes are attached at regular spacings to a curved beam which, using the tractor PTO, is lifted to be just above the tree canopy.
- The tractor is then slowly driven down the alley pulling the ropes through the trees and knocking off many of the flowers.
- The crudest machines, which drag knotted ropes through trees to knock off blossoms, cause considerable damage to the trees and cannot currently be recommended in the UK.

#### Trials conducted in Switzerland

Trials conducted in Switzerland (Bertschinger et al., 1998) have focused on using what is known as the 'wire-machine' (designed by H. Gessler, Friedrichshafen-Hirschblatt, Germany).

- The machine is powered by and pulled by a conventional orchard tractor (Schröder, 1996).
- It comprises a vertically turning axle with nylon wires of approximately 40 cm long attached.
- The tractor is driven at approximately 4 km/h and the wires on the axle rotate at 1500 revolutions/min.
- Further details of this machine can be gleaned from Stadler et al., (1996) and from the UK importer N P Seymour.

- Thinning efficacy was not adequate on pyramidal shaped trees with branches longer than 70 cm and this was especially true on the tree tops and in the centres, close to the central leader.
- Some increases in pests (aphids) and diseases were noted on the machine-thinned trees.
- The authors concluded that for machines of the type described to be effective, tree architecture must be adapted significantly.
- Slender cylindrical trees with short branches would be ideal.
- Further research is warranted on the development of orchard canopy systems and suitable machines for mechanised flower and/or fruitlet thinning in UK apple orchards.

#### Chemical methods of thinning apple flowers

Most chemicals that have been tested and found effective in preventing apple flowers from setting fruits work by desiccating the flower organs and preventing pollination and/or fertilisation (fruit set). There are a number of chemicals that work in this way but the only one currently available to UK growers is the nutrient ammonium thiosulphate (ATS).

Other blossom thinners that have shown promise in trials both in the UK and abroad are:

- Elgetol (DNOC)
- Endothallic acid
- Lime sulphur
- Pelargonic acid
- Wilthin
- Armothin
- Ethephon
- Urea
- Zinc
- Vinegar
- Common salt (sodium chloride)

Other chemicals applied at the time of flowering for flower thinning may be effective through a different action to those listed above.

- Ethephon releases the gas ethylene and stimulates the drop of flowers and young fruitlets.
- Part of the thinning reaction induced by high rate urea sprays is undoubtedly attributable, indirectly, to the damage the sprays cause to the primary leaves surrounding the flowering spurs.
- The mode of action of zinc in causing thinning is not understood.
- The auxin naphthylacetic acid (NAA–Planofix) has also been applied close to full bloom as an apple thinner.
- This is thought to trigger the early drop of flowers and fruitlets by causing a temporary check to the production and movement of foodstuffs (carbohydrates) to the flowers.

#### Ammonium thiosulphate (ATS) for blossom thinning

The foliar nutrient ATS has a very useful side effect as a blossom thinner on apples and other crops. If applied at flowering time, ATS works by desiccating and, therefore, damaging the stigmas and styles of apple flowers, so preventing them from setting fruits.

When using ATS as a blossom thinner on apples it is important to consider:

- Spray timings
- The ideal weather conditions
On this limited preliminary evidence, Armothin appears to hold only minimal promise as a potential blossom thinner for apples under UK conditions.

A third trial conducted on the variety Jonagold was also disappointing with only minimal thinning following the Armothin sprays.

A second trial on Royal Gala also included sprays of Armothin, applied 10 days after full bloom. The results of the two trials were inconsistent.

Armothin is a surfactant manufactured by the Azco-Nobel Co Ltd, which has showed useful activity as a blossom thinner on stone fruits. It is a 98% fatty amine polymer.

Spray timings

Trials conducted at East Malling and in Denmark have shown that flowers which are at the balloon stage through to those that have been open for 2 days are the most sensitive to the sprays.

- Although the petals of flowers at the pink bud stage are damaged by ATS sprays, the flowers still remain capable of setting fruits.
- Flowers that have been open for more than two days and have been pollinated by bees will often still set fruits, despite being damaged by the ATS sprays.
- This is because the fruit receptacles and ovaries are not damaged by the sprays and once pollen tubes have penetrated the ovary they will not be influenced by the sprays.
- Nevertheless, in certain climatic conditions, such as very slow drying, the skin finish of these fruits may be slightly damaged.

In seasons when flowering is concentrated over just a few days, then a single treatment with ATS will often be sufficient to thin the trees effectively.

- This is because a high proportion of the total number of flowers will be at a vulnerable stage on the day of the spray treatment (70% full bloom).

In years when the blossoming period is extended two sprays may be required; the first when 25% of the blossoms have opened and a second when most of the spur flowers have opened.

- A single spray in such seasons is rarely sufficient to effect adequate thinning.

With varieties that are prone to set large numbers of fruits on one-year-old wood (axillary blossoms) growers often endeavour to selectively prevent this fruit set using sprays of ATS applied after full bloom.

- Axillary blossoms, which often give rise to smaller than average fruits at harvest, flower several days after spur blossoms.
- To thin them ATS sprays must be delayed until early petal fall on spur blossoms.
- Care must be taken with this late treatment, however, as trials in Denmark have shown that in their climatic conditions (high humidity and slow drying) sprays applied to thin axillary blossoms may also damage and cause abortion of fruitlets already set on the spur blossoms.
- Although this is contrary to the results noted at East Malling, it does indicate that there is a potential problem with this strategy in some climatic conditions.

Trials at East Malling (Webster and Spencer, 1999, Webster and Spencer, 2000), on the varieties Royal Gala and Queen Cox, showed that, although single sprays with ATS usually thinned very effectively in the first year of treatment, repeating the same sprays on the same trees in the subsequent season could produce disappointing results.

- The reason for this was the very abundant blossom numbers induced in the second year by the treatments in the first year.
- Although the treatments reduced set per 100 flower buds similarly in both seasons, the thinning was insufficient in the second season to compensate for the big increase in flower numbers.
- Where this is likely to be a problem, growers should consider increasing spray volumes, or ATS concentrations or even applying a second spray during the flowering period.

The ideal weather conditions

Research conducted in controlled environment chambers in Holland has shown that as temperatures increase the degree of thinning achieved with ATS sprays also increases.

- So, when temperatures are 15°C or higher thinning should be very efficient. In contrast, when temperatures are very cool <10°C the sprays are likely to prove much less effective.
- Temperatures are influential, not just at the time of spraying but for several hours after the treatment is applied.

Thinning is also influenced by the humidity at the time of spraying. Slow drying conditions (high humidities) improve thinning slightly, but may also cause phytotoxicity on the spur leaves.

- Spraying high concentrations of ATS in slow drying conditions is not recommended on account of the potential problems of phytotoxicity to the spur leaves.
- Spur leaves are essential to the early growth of the persisting fruitlets.

Research in Canada has indicated that when sprays of ATS are applied at low volumes the spray concentration needs to be increased as much as 6 to 12 times (Sanders and Looney, 1993).

- Such concentrations can, however be very phytotoxic (Irving et al., 1989) and further work is needed before similar recommendations can be made for UK conditions.
- However, in contrast to the above findings, recent work conducted in Poland indicates that ATS thins best if applied at higher concentrations and low spray volumes.
- Differences in climatic conditions between Canada and Poland may help explain these anomalies.

Armominth

Armominth is a surfactant manufactured by the Azco-Nobel Co Ltd, which has showed useful activity as a blossom thinner on stone fruits. It is a 98% fatty amine polymer.

- In trials at East Malling, high volume sprays (1000 l/ha) of Armominth at 0.5% active ingredient were tested at three timings, balloon blossom, 5 days after full bloom on the two-year-old spurs or 10 days after full bloom (Webster and Spencer, 2000).
- The trees used for the test were eight-year-old Royal Gala on M.9 rootstock.
- Concern was expressed by the chemical manufacturers about possible fruit russetting.
- To counteract this a programme of Regulex (GA4+7) was applied to some of the Armominth treated trees.

A second trial on Royal Gala also included sprays of Armominth, applied 10 days after full bloom. The results of the two trials were inconsistent.

- In one trial no significant thinning was achieved, whilst in the other, mean fruit size and grade out was improved in comparison with unsprayed controls.
- No significant phytotoxic damage was recorded, irrespective of whether the treatments were supplemented by Regulex sprays or not.

A third trial conducted on the variety Jonagold was also disappointing with only minimal thinning following the Armominth sprays.

On this limited preliminary evidence, Armominth appears to hold only minimal promise as a potential blossom thinner for apples under UK conditions.

- ‘Armominth’ has proved an effective thinner for stone fruits in Italian trials.
Pelagonic acid (60% a.i v/v) is registered in the USA as a blossom thinner under the trade name of 'Thinex'.

Taking all the evidence into account ethephon produces a very variable thinning response, ranging from almost no thinning to total inhibition of fruit set, even in climatic conditions much more stable than those experienced in the UK. It is unlikely, therefore, that ethephon can be used with any reliability as a flower thinner in UK orchards.

Endothallic acid (Endothall)

European and USA researchers devoted much R&D effort in the 1990s to testing the efficacy of endothallic acid (TD 2337-2 or 'Endothall') as a blossom thinner for apples. The chemical is a 5% (w/w) active ingredient formulation of 2-potassium-7-oxo-bicyclo (2,2,1) heptane-2-carboxylate and it is approved for use in some countries as an aquatic weedkiller.

In trials at East Malling, it was tested as a blossom thinner for Royal Gala and Queen Cox at rates of 500, 1000 and 2000 ppm high volume (1000 l/ha) sprays (Webster and Spencer, 1999, Webster and Spencer, 2000).

Most of the treatments had some thinning effect and the thinning severity was related to spray concentration.

In the first year of treatment, the sprays increased grade-outs of large size fruits.

However, although treatment of the same trees in the second year also reduced fruit set, no improvements in final fruit sizes were achieved.

This was explained by the large differences in flower abundance on the trees at the start of the second year.

Treatments in the first year increased flower density in the second year very significantly, whilst overcropping of the unthinned controls in the first year reduced flower density in the subsequent season.

Although the sprays reduced percentage fruit set in both years, this was insufficient in the second year to compensate for the large increase in flow eiring on the previously treated trees.

In these situations two or more sprays of a chemical thinner may prove necessary in seasons or situations of high flower abundance.

No phytotoxicity to leaves or fruits was observed in UK trials. However, phytotoxicity and variable responses were recorded in USA trials with this product (Andrews and Collier, 1995).

Although proven quite effective as a blossom thinner in European trials, work on endothallic acid has now ceased.

Endothallic acid (Endothall) is not approved currently for use as a flower thinner in UK orchards.

Ethephon

Ethephon (Ethrel C) has been tried on many occasions as a blossom thinner for apples (Irving et al., 1989).

However, the sensitivity of apple flowers varies greatly with the stage of flower development.

Apple flowers show high sensitivity at the pink bud stage but almost no sensitivity by the time of petal fall (Veinbrants and Hutchinson, 1976).

Also, the thinning action of ethephon is highly dependent upon temperature at the time of spraying and during the subsequent 24 hours.

Temperatures lower than 15°C result in poor efficacy of thinning; thinning increases linearly as temperatures increase from 12-24°C (Jones and Koen, 1985).

For the ethylene (which stimulates the thinning response) to be released efficiently by ethephon it is also essential that the spray solution is alkaline.

Although ethephon has fallen from favour as a blossom thinner since the 1980s, more recent work in Australia shows that with appropriate timing it can perform well with the variety Fuji (Jones et al., 1990).

With this variety thinning can be achieved with sprays applied either at full bloom or 14 days later (Jones et al., 1989).

However, the authors also showed that the concentrations necessary for effective thinning varied with the rootstock.

On the strong growing seedling rootstocks only 25-50 ppmw as required, whilst on MM.106 rootstock 100-200 ppmw as necessary.

Variability of response is also influenced by the spray volume used (Koen et al., 1996).

Research conducted at East Malling in the 1980s (Knight et al., 1987) showed that ethephon at 500 ppm could be an effective thinner for the variety Spartan.

More recent evidence from Norway indicates that sprays of 300 ppm at early bloom can be effective in thinning the early ripening variety Summerred.

The new variety Debush (Tipton) has also been effectively thinned in Dutch trials using sprays of ethephon applied when 20% of the flowers are open.

Taking all the evidence into account ethephon produces a very variable thinning response, ranging from almost no thinning to total inhibition of fruit set, even in climatic conditions much more stable than those experienced in the UK.

It is unlikely, therefore, that ethephon can be used with any reliability as a flower thinner in the UK.

In regions of the world where temperatures during blossom time are >15°C, sprays of ethephon in water with a slightly alkaline pH often give consistent beneficial effects in apple flower thinning.

Where temperatures are lower, the thinning response to ethephon is usually variable and often very poor.

Ethephon is cleared for use in many European countries as an aquatic weedkiller.

Pelargonic acid

Pelargonic acid (60% a.i v/v) is registered in the USA as a blossom thinner under the trade name of 'Thinex'.

Trials in the USA have shown it to have some useful activity as a blossom thinner (Williams, 1994).

However, in trials conducted at East Malling and by researchers in Holland the product performed poorly as a blossom thinner and caused significant phytotoxicity to spur leaves (Webster, and Spencer, 1999, Webster and Spencer, 2000).

In the East Malling trials, rates of 750-3000 ppm were compared in high volume sprays to the varieties Royal Gala and Queen Cox. Phytotoxicity and variable responses have also been observed in USA trials with this product (Andrews and Collier, 1995).

Pelargonic acid seems to offer little promise as a flower thinner in UK climatic conditions.

Pelargonic acid is not approved currently for use as a flower thinner in UK orchards.
Urea

Urea has been tested and used as a blossom thinner for apples in Germany for many years.

- It is recommended at 3% to 4% high volume sprays and is especially useful with varieties prone to biennial bearing, such as Elstar (Graf, 1997).
- The product seems to bring about its thinning action by scorching the spur leaves.
- Where no spur leaf damage is noted, thinning is often poor. One of the concerns with this urea strategy to thinning is that early loss of spur leaves may well reduce calcium uptake and increase subsequent problems with bitter pit (Volz et al., 1994).
- Growers using urea as a blossom thinner should also be aware that it may lead to poorer fruit colour at harvest, fruit russetting and reduced flowering in the subsequent season (Wartheim, 1997).
- Urea at concentrations of 3-4% has given good, albeit inconsistent, effects as a flower thinner on apples in German and Danish trials.
- However, urea causes considerable damage to the spur leaves and for this reason appears to have little potential as a thinner in UK conditions.
- Urea is not approved currently for use as a flower thinner in UK orchards.

Within

A 79% active ingredient formulation of monocarbaamide-dihydrogen sulphate (MCDS or sulfcarbamide), which is marketed in the USA as ‘Wilthin’, has shown promise in USA trials as an apple thinner (Williams, 1994).

- Trials using the product in high volume sprays at 1000 ppm Queen Cox and Royal Gala at East Malling proved less successful (Webster and Spencer 1999; Webster and Spencer, 2000).
- Trials conducted at East Malling in the 1980s showed that zinc sprays applied during flowering reduced fruit set but, as applications in the previous year also increased flower bud abundance, this negative effect was cancelled out (Yogaratnam and Greenham, 1982).
- Sprays of 1.0 g l⁻¹ zinc (as 4.4 g ZnSO₄·7H₂O l⁻¹ mixed with a propriety wetting agent), applied in 1998 at high volume to semi-mature Brantley’s Seedling apple trees on M9 rootstock, reduced initial fruit set by 17%.
- Sprays of 1.0 g l⁻¹ zinc increased flower bud abundance, this negative effect was cancelled out (Graf, 1997).
- Sprays containing the trace element zinc are often recommended for improving fruit quality of harvested apples.
- Trials using the product in high volume sprays at 1000 ppm Queen Cox and Royal Gala at East Malling proved less successful (Webster and Spencer 1999; Webster and Spencer, 2000).
- Trials conducted at East Malling in the 1980s showed that zinc sprays applied during flowering reduced fruit set but, as applications in the previous year also increased flower bud abundance, this negative effect was cancelled out (Yogaratnam and Greenham, 1982).
- Although effective in USA trials on apples, ‘Wilthin’ gave disappointing results as a thinner in UK trials.
- ‘Wilthin’ is not approved currently for use as a flower thinner in UK orchard.

Zinc

Sprays containing the trace element zinc are often recommended for improving fruit quality of harvested apples.

- Trials conducted at East Malling in the 1980s showed that zinc sprays applied during flowering reduced fruit set but, as applications in the previous year also increased flower bud abundance, this negative effect was cancelled out (Yogaratnam and Greenham, 1982).
- More recent trials, conducted at East Malling (Hipps, personal communication), indicate that sprays applied during the stage of active cell division in fruitlets (i.e. in the few weeks following petal fall) can, on occasions, stimulate thinning.
- Sprays of 1.0 g l⁻¹ zinc (as 4.4 g ZnSO₄·7H₂O l⁻¹ mixed with a propriety wetting agent), applied in 1998 at high volume to semi-mature Brantley’s Seedling apple trees on M9 rootstock, reduced initial fruit set by 17%.
- However, similar sprays in 1999 had no effect on fruit set. Further research is needed to understand the variable effect of zinc on fruit abscission.
- The thinning potential of sprays of zinc products needs further investigation.

Vinegar

- In HDC project TF 148 (Thinning of apple flowers using chemicals sensitive to the environment) trials conducted at East Malling showed that undiluted vinegar applied at full bloom of the spur buds was an effective thinner but significantly increased skin russet.

Common salt (sodium chloride)

In HDC project TF 148 (Thinning of apple flowers using chemicals sensitive to the environment) trials conducted at East Malling showed that common salt (sodium chloride) applied at full bloom of the spur buds was an effective thinner.

- Growers may be interested in applying common salt to small areas of orchard at a time when they would normally apply ATS.
- It is advisable to apply 12 g of common salt per litre of water applied at high volume.
- Although 16 g per litre of water is likely to be more effective, in view of the evidence from abroad that this may result in over-thinning, interested growers may like to compare the effects of the two rates in small areas of orchard.

Chemical thinning with benzyl adenine (BA: ’Perlan’, ’Accel’, ’Paturyl’, ’Expander’)

With the impending withdrawal of Carbaryl in Europe, scientists have been seeking alternative fruitlet thinners for apples.

- One product that has shown some promise in trials mainly in the USA is benzyl adenine (BA). Approval has been gained in some European countries.
- Trials conducted at East Malling have produced variable results with BA, as shown below.

Thinning Royal Gala with BA

In trials conducted in 1995 and 1996 at HR-East Malling and funded by AFFC (Webster and Spencer, 2000), sprays of benzyl adenine (BA, Paturyl formulation) at concentrations ranging from 50 ppm to 200 ppm reduced percentage final set on Royal Gala trees.

- On this preliminary evidence BA appeared not to hold much potential as a fruitlet thinner for Gala.
- However, the sprays, which were applied at the 12 mm fruitlet diameter stage, had only small and insignificant effects on fruit size and grade out.

Effects of sprays of BA (Paturyl, Accel or Perlan) on the fruit set, yield and fruit size of Royal Gala (sprays at 12 mm stage ~100 ppm in 1000 litres/ha)
Further research is needed on Gala clones to find strategies for reducing this inconsistent thinning response to BA.

**Thinning Queen Cox with BA**

Sprays of BA applied at the 12 mm fruitlet diameter stage to Queen Cox trees in 1995 reduced final fruit set/100 floral buds and increased mean fruit size and grade out of the larger Class I fruits (Webster and Spencer, 2000).

- The most effective spray concentration was 100 ppm applied in high volumes of water.
- The sprays caused no significant reduction in total yields/tree.

### Effects of BA sprays on the fruit set and yields of Queen Cox in 1995

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Final set/100 floral buds</th>
<th>Total yield/tree (kg)</th>
<th>Mean fruit wt. (g)</th>
<th>Class I (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;70 mm</td>
</tr>
<tr>
<td>Unthinned</td>
<td>105</td>
<td>13.0</td>
<td>84.3</td>
<td>9.6</td>
</tr>
<tr>
<td>BA 50 ppm</td>
<td>75</td>
<td>11.8</td>
<td>105.0</td>
<td>17.0</td>
</tr>
<tr>
<td>BA 100 ppm</td>
<td>66</td>
<td>11.0</td>
<td>107.6</td>
<td>13.6</td>
</tr>
<tr>
<td>BA 200 ppm</td>
<td>68</td>
<td>11.4</td>
<td>116.2</td>
<td>38.3</td>
</tr>
<tr>
<td>Carbaryl 750 ppm</td>
<td>54</td>
<td>9.8</td>
<td>117.9</td>
<td>20.1</td>
</tr>
</tbody>
</table>

Although the BA sprays reduced fruit numbers/100 floral buds, when applied for the second year (1996) to the same trees, this thinning was insufficient and failed to compensate for the much increased blossom abundance stimulated by the sprays applied in 1995.

Consequently, fruit sizes were not improved in 1996.

Further trials using BA as a fruitlet thinner for Queen Cox are warranted.

**Thinning Jonagold with BA**

Sprays of BA (100 ppm) applied at the 12 mm fruitlet stage to ‘Jonagold’ trees in 1998, improved fruit size and grade out, although the benefits were less than those achieved with hand thinning.

### Effects of BA (Paturyl, Accel or Perlan) sprays on the fruit set, yield and fruit size of Jonagold in 1998 (sprays applied at 100 ppm in 1000 litres/ha at the 12

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Final set/100 floral buds</th>
<th>Total yield/tree (kg)</th>
<th>Mean fruit wt. (g)</th>
<th>Class I (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;70 mm</td>
</tr>
<tr>
<td>Unthinned</td>
<td>146</td>
<td>24.5</td>
<td>11.5</td>
<td>94</td>
</tr>
<tr>
<td>Paturyl</td>
<td>140</td>
<td>25.2</td>
<td>39.7</td>
<td>111</td>
</tr>
<tr>
<td>Accel</td>
<td>132</td>
<td>26.5</td>
<td>30.8</td>
<td>101</td>
</tr>
<tr>
<td>Perlan</td>
<td>126</td>
<td>26.1</td>
<td>29.7</td>
<td>109</td>
</tr>
</tbody>
</table>
### Trials in continental Europe with BA

- In trials conducted in mainland Europe, sprays of 100 ppm proved ineffective in thinning the early ripening variety Summered in Norwegian trials.
- However, in Swiss trials, sprays of the same concentration increased the mean size of Boskoop fruits at harvest.
- Results on the variety Golden Delicious have been variable with no benefits reported in Switzerland but improved fruit size reported in Spain.
- In trials conducted in Slovenia, mixtures of BA and NAA have proved effective in thinning Gala.
- In German trials BA has also proved an effective thinner for the varieties Débrou Éstivale and Pinova.
- In Italy, BA, which is known under the trade name of ‘Expander’, has proved effective in thinning Royal Gala when applied at 100 ppm at the 10 mm fruitlet diameter stage and trials on the variety Fuji have also shown good thinning responses from BA at 200 ppm.
- On the variety Pink Lady, trials in France show that BA (150 ppm) was an effective thinner applied at the 15 mm fruitlet diameter stage.
- Recent work conducted in Poland indicates that thinning with BA increases with increasing concentrations up to 200 ppm and that it is improved by use of high spray volumes.

BA has shown promise in thinning apple fruitlets in trials conducted in several countries.

- More work is needed on this thinner if the inconsistencies of response are to be understood and overcome.
- BA is not approved currently for use as a thinner in UK orchards.

### Other chemicals trialled for fruitlet thinning

**Chemical thinning with NAA and NAAm (NAD)**

NAA, or its amide NAD (NAAm), has long been used in continental Europe for thinning apples.

- Although approved for use in the UK up until the 1970s, these auxins failed to prove consistently effective when used on Cox’s Orange Pippin and they were withdrawn from use.

**NAA**

Thinning results using NAA are very variable from season to season, variety to variety and site to site.

- In recent years, it has proved consistently effective only in Ripeish trials.
- NAA is either sprayed a little later than NAAm (up to 14 days after petal fall), or during flowering.
- Concentrations of up to 20 ppm are used and many different wetters and surfactants have been tested in attempts (largely unsuccessful) to improve the consistency of response.
- However, recent work in Germany has provided some explanation of the variability of response and made suggestions for future use of more appropriate wetters (Schönherr et al., 2000).
- Recent trials in Norway have shown NAA to be ineffective in thinning the early ripening variety Summered, when applied at the 10 mm fruitlet diameter stage.

**NAAm (NAD)**

Trials on several varieties grown in central Germany (Link, 1998) showed that the NAAm thinned Cox in some situations but did not result in any increase in monetary value when the results of trials over an eight year period were analysed.

- In contrast, hand thinning either by removing whole blossom clusters at the time of flowering or of fruitlets after completion of ‘June Drop’, usually produced more economically worthwhile results.

### Effects of thinning treatments on the yields and grade-outs of Cox grown in Hohenheim, Germany (mean of years 1982-1990)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Final set/100 floral buds</th>
<th>Total yield/tree (kg)</th>
<th>Mean fruit wt. (g)</th>
<th>% Class I &gt;90 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unthinned</td>
<td>62</td>
<td>39.2</td>
<td>186</td>
<td>0.1</td>
</tr>
<tr>
<td>Hand thinned</td>
<td>34</td>
<td>29.2</td>
<td>262</td>
<td>27.8</td>
</tr>
<tr>
<td>Paturyl</td>
<td>51</td>
<td>37.4</td>
<td>223</td>
<td>15.5</td>
</tr>
<tr>
<td>Accel</td>
<td>43</td>
<td>31.8</td>
<td>238</td>
<td>24.1</td>
</tr>
<tr>
<td>Perlan</td>
<td>52</td>
<td>37.2</td>
<td>219</td>
<td>11.3</td>
</tr>
</tbody>
</table>
Recent trials in Germany have shown good thinning of the variety Delbard Estivale using a combination of NAAm and Ethrel applied at the late bloom stage. NAAm in liquid formulations is normally applied at a concentration of 40 ppm in high volume sprays of 1500 l/ha just after petal fall. However, concentrations of up to 100 ppm have been used in some situations. It is normally sprayed shortly after flowering.

In the absence of carbaryl or other potential fruitlet thinning chemicals NAAm is likely to remain a major thinner in many orchards in mainland Europe. NAA and NAAm are still approved for use as fruitlet thinners on apples in many European countries. However, they are not approved on apples. The thinning effects achieved are inconsistent and further work is needed on ensuring that the pH of the water used is optimal and that the best surfactants are used.

Chemical thinning with Ethephon (Ethrel C)

Ethephon (Ethrel C) applied at the 12 mm fruitlet diameter stage has been shown to thin many varieties of apple.

- Unfortunately, the results are extremely variable from season to season and between varieties.
- A major influence on the efficacy of Ethrel sprays in thinning is the temperatures during and shortly after treatment.
- Unless the day temperatures are 15°C or above, the response to the sprays is likely to be poor.
- Another factor influencing the variability of response of Ethrel thinning sprays is the pH of the water used.
- Alkaline spray solutions are needed to maximise the release of ethylene by the product.

Knight (1981) showed that sprays at concentrations of 150 ppm were effective in thinning Discovery but that the growth rate of the persisting fruitlets was often reduced by the treatment.

Similar effects on fruit growth rates have also been noted in Dutch trials.

Although still used in several European countries as a thinner, Ethrel is extremely variable under UK climatic conditions and in some situations may cause slight russetting and poor storage potential in fruits.

The results achieved with Ethrel are often variable. Thinning efficacy is improved by temperatures higher than 15°C and by use of alkaline water.

Ethephon (Ethrel) is still approved as a fruitlet thinning chemical for apple in several European countries, but is not approved for this use in the UK.

Inducing thinning by shading trees

Research conducted in the USA in the late 1980s showed that thinning of apple trees could be enhanced by shading the trees (Byers et al., 1991). Severe shading for brief periods during the development of apple fruitlets can induce fruit drop.

Attempts were made to verify the USA trials in further work conducted in Switzerland (Bertschinger et al., 1998) where structures used to support hail netting were used to create shade within orchards.

- The shade was created using polypropylene sheeting and 50% and 100% shade levels were imposed for 5 days at either 14 or 28 days after full bloom to ten-year-old trees of Arik and Jonagold on M9 rootstocks.
- The ideal level of fruit set was achieved using the 100% shade for 5 days commencing 14 days after full bloom.
- This fruit set was equivalent to that obtained by hand thinning after June drop.
- Fruit quality and yield productivity were acceptable with this treatment.
- Application of 100% shading 28 days after full bloom caused 100% fruit drop.

Although successful in the Swiss trial, shading as a means of fruitlet thinning does carry some inherent risks.

- It is known that shading reduces relative growth rates of fruitlets in the period of 1 to 5 weeks after full bloom.
- This is the phase of cell division and other studies have shown that reductions in growth in this period may result in reductions in yield (Lakso et al., 1989).
- Similarly, it has been shown in Italian studies that moderate shading (40% normal light) of extension shoots three weeks after full bloom suppresses the movement of carbohydrates to fruits.
- Further studies are needed before this non-chemical strategy for inducing fruit drop can be recommended.
Combined flower and fruitlet thinning treatments

Thinning treatments used with considerable success in North America for many years comprised a spray of Elgetol (DNOC) as a flower thinner, followed by sprays of carbaryl or NAAm.

- Recently, researchers at East Malling have investigated the use of other, more environmentally sensitive combinations of spray treatments to achieve effective apple thinning.

Royal Gala

- In a trial conducted in 1998, a spray of ATS (0.5 or 1.0%) at full bloom, followed by a spray of BA (Perlan 100 ppm), all at high volume (1000 litres/ha), showed some promise for thinning the variety Royal Gala.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Final set/100 floral buds</th>
<th>Total yield/tree (kg)</th>
<th>Mean fruit wt. (g)</th>
<th>Yield/tree Class I (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;70 mm</td>
</tr>
<tr>
<td>Unthinned</td>
<td>183</td>
<td>27.7</td>
<td>101</td>
<td>7</td>
</tr>
<tr>
<td>ATS (0.5%) + BA (100 ppm)</td>
<td>131</td>
<td>23.7</td>
<td>122</td>
<td>13</td>
</tr>
<tr>
<td>ATS (1.0%) + BA (100 ppm)</td>
<td>105</td>
<td>21.2</td>
<td>130</td>
<td>13</td>
</tr>
<tr>
<td>Hand thinned</td>
<td>66</td>
<td>14.2</td>
<td>138</td>
<td>11</td>
</tr>
</tbody>
</table>

Jonagold

- Combined treatments of 0.5% ATS, applied at full bloom, followed by 100 ppm BA, at the 10-12 mm fruitlet diameter stage, gave promising thinning results on Jonagold trees in 1998.

- Although the degree of thinning was much less than that achieved by hand, reductions in total yield were less.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Final set/100 floral buds</th>
<th>Total yield/tree (kg)</th>
<th>Mean fruit wt. (g)</th>
<th>% Class I &gt;90 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unthinned</td>
<td>57</td>
<td>44</td>
<td>179</td>
<td>0.5</td>
</tr>
<tr>
<td>ATS (0.5%) + BA (100 ppm)</td>
<td>47</td>
<td>42</td>
<td>208</td>
<td>13.4</td>
</tr>
<tr>
<td>ATS (1.0%) + BA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Consider supplementing any blossom thinning, achieved using ATS, with supplementary hand thinning at the 12 mm fruitlet diameter stage.

Recently, promising results have been achieved using combinations of ATS for blossom thinning and BA for fruitlet thinning.

However, BA is not currently approved for use as a fruitlet thinner in the UK.

**Combined chemical thinning strategies tested abroad**

Trials conducted in mainland Europe have on occasions shown the benefits of using more than one chemical for thinning apples.

- Trials in the Netherlands have recently shown that a combination of the flower thinner lime sulphur and the fruitlet thinner BA can prove effective on the variety Elstar.
- In Spanish trials, mixtures of Ethrel (applied at 20% open flower) and BA (applied at the 10 mm stage) have thinned Fuji effectively, as have combinations of NAA and carbaryl.
- Similarly, Gala and Golden Delicious were very effectively thinned with mixtures of BA and NAA in Slovenia.
- The same combination of chemicals has proved effective in thinning the variety Elstar in Dutch trials.
- In Northern Italy sprays of NAAm or Ethrel, followed by later sprays of BA have proved very effective in thinning Royal Gala.
- However, in French trials this combination treatment overthinned the variety Pink Lady.

**The natural abscission of flowers and fruitlets**

According to Bangerth (2000) there are, currently, two hypotheses advanced to explain the abscission of young apple fruits:

- Abscission is caused by insufficient supply of assimilate to fruitlets as a result of limited assimilate production and/or allocation to the fruit.
- Abscission is caused by a regulatory hormonal mechanism by which the plant protects specific fruits from assimilate limited growth later in the season.

Although there is some support for the first hypothesis (Stopar, 1998), abscinding apples often have equal or higher amounts of carbohydrates in them compared with the persisting fruits (Abuzzese et al., 1995).

In recent years, therefore, research has focused on understanding how hormones influence fruitlet abscission, although the causes of abscission are probably due to a combination of hormonal and assimilate supply factors.

The general hypothesis concerning abscission is that various factors influence the balance of auxins and ethylene around the abscission zone, and also influence the receptivity of the tissues in this zone to either auxin (prevents abscission) or ethylene (stimulates abscission).

- For instance, reductions in the supply of foodstuffs (produced by photosynthesis) to the fruit, will in turn reduce the amounts of auxins that are produced and transported from the seeds out of the fruitlets.
- This renders the abscission zone more sensitive to ethylene stimulated abscission.
- Low light levels in the orchard can reduce photosynthesis, as can applications of the synthetic auxins NAA or NAAm or inhibitors of photosynthesis such as terbacil.
- The processes involved are much more complicated than described here and new information continues to improve our knowledge.
- For a fuller account of the biochemical and molecular processes controlling fruitlet abscission the reader should consult Bangerth (2000) and Bonghi et al., (2000).

Where trees are carrying a very heavy crop, the most vulnerable fruitlets to abscission are those that set slightly later and are, therefore, slightly smaller (Bangerth, 1989).

- Problems can be experienced occasionally where most fruitlets are of similar size and 'sink strength'.
- In this situation, when conditions reducing assimilate supply are experienced, fruit drop may be excessively severe.
- Where trees develop vigorous growth of extension or bourse shoots, natural fruit drop may also be severe.
- This is thought to be due to the strong competition between the shoots and the fruits for vital assimilates (Bangerth, 1986).
- Competition also seems to play an earlier role, in that when floral abundance is very high, the levels of fruit set (per 100 flowers) are invariably lower than when floral abundance is lower (Jones and Koen, 1986).
- Indeed, work at East Malling showed that diminishing competition between flowers by removal of some of them increased the set of the remaining flowers (Knight et al., 1987).

Research conducted at East Malling has shown that carbon assimilation and its partitioning either from dormant season reserves held in the woody tissues of the tree or from current leaf photosynthesis is influential in fruit set and development.

- Fruit set can be depressed by the removal of the first leaves to emerge on the tree in the spring (the spur leaves) (Ferree and Palmer, 1982).
- The same research showed that the early removal of the bourse shoot could also reduce initial fruit set but increased final yields.
- This apparent paradox is probably explained by the removal of bourse leaves initially reducing assimilate supply and inducing fruit drop but, later, lack of bourse shoots reduces potential competition for assimilates by the bourse shoot as the persisting fruits grow.

Whilst spur leaf removal may appear an attractive method of early thinning, this is not recommended as these leaves are vital for the uptake of calcium into the fruits, as shown by complementary work at East Malling (Jones and Samuelson, 1983).
Hormones occurring within the tree that are associated with flower and fruitlet abscission

Several natural plant hormones have been implicated in the tree processes leading to flower and/or fruitlet abscission (drop).

- Auxins
  - NAA (N-(naphthyl)acetic acid) and its amide NAAm (NAD) are used to thin the flowers or fruits. NAAm is the amide of NAA and is more active than NAA. Concentrations of NAA are usually up to 20 ppm whilst those for NAAm are up to 100 ppm. NAAm is usually applied soon after flowering, whilst NAA is applied a little later, although it may also be used during flowering.
  - NAAm (NAD) is more active than NAAm.
  - In one experiment, NAAm was applied in water with a pH >7 almost eliminated any cuticular penetration, even at high humidities (100%) and moderate temperatures (20°C).
  - However, applications in water with a pH <7 almost eliminated any cuticular penetration, even at high humidities (100%) and moderate temperatures (20°C).
  - However, applications in water with a pH <7 almost eliminated any cuticular penetration, even at high humidities (100%) and moderate temperatures (20°C).
  - NAAm is destroyed by UV light and sprays are best applied in the late afternoon or early evening.

Applications of plant growth regulators to induce flower and fruitlet abscission

Several types of chemicals have been shown to have thinning action when sprayed onto apple trees.

- Hormones occurring naturally within the tree that are associated with flower and/or fruitlet abscission (drop).
  - Leaf removal in these trials also reduced fruit calcium levels at harvest and removal of bourse shoots reduced return bloom in the subsequent season.
  - The most severe reductions in fruit set on Cox were brought about by removal of spur leaves in the period between full bloom and two weeks later (Proctor and Palmer, 1981).
  - Leaf removal in these trials also reduced fruit calcium levels at harvest and removal of bourse shoots reduced return bloom in the subsequent season.

- Auxins
  - Concentrations of NAA are usually up to 20 ppm whilst those for NAAm are up to 100 ppm.
  - NAAm is usually applied soon after flowering, whilst NAA is applied a little later, although it will also thin if used during flowering (Jones et al., 1989).
  - Concentrations of NAA are usually up to 20 ppm whilst those for NAAm are up to 100 ppm.
  - The liquid formulation of NAAm is more active than the powder formulation.

- The liquid formulation of NAAm is more active than the powder formulation.

- Importance of the responsiveness of the tissues associated with the abscission zone to either auxins or ethylene. Auxins move from the seeds or other tissues of fruits back into the fruit stalk and spur; this is referred to as basipetal movement.

During the opening of apple flowers the unfertilised ovules show very little growth and the production and export of auxins is low (Gruber and Bangerth, 1990).

- Ethylene releasing chemicals
  - The flowers are, therefore, vulnerable to ethylene-induced abscission during this phase (Wertimeh, 1997).

- Photosynthesis inhibiting chemicals
  - Pollination, pollen tube growth and fertilisation of the ovules and subsequent seed growth all lead to a significant increase in hormone activity in the ovary.

- Cytokinins (benzyl adenine – BA)
  - The auxins diffusing from the ovary help prevent abscission.

- New chemicals showing some potential as thinners
  - The auxins diffusing from the ovary help prevent abscission.

- Another idea is that they restrict the supply of assimilates (foodstuffs) to the developing fruitlets either directly or indirectly by causing a temporary reduction in photosynthesis (Schneider, 1978a; 1978b).

Variable weather conditions during or after application of NAA affects their uptake and may also influence its transport and breakdown within the apple tree.

- Uptake through apple leaves increases with increasing temperatures (Black et al., 1995) and is also increased in low light conditions (Flore et al., 1990).

- The effect of humidity on the efficacy of NAA thinning is often important (Jones et al., 1989) but is also inconsistent.

- However, spraying NAA after cool moist weather may increase rather than decrease fruit set and retention.

- NAA and NAAm sprays also induce unwanted "pygmy" fruits, especially in varieties such as Elstar.

More recent studies in Germany (Schöntherr et al., 2000) have demonstrated that penetration of NAA through leaf cuticles is approximately 40% in eight hours, if applied in deionised water.

- However, applications in water with a pH >7 almost eliminated any cuticular penetration, even at high humidities (100%) and moderate temperatures 20°C.

- Rates of penetration were much lower in the deionised water if applied at only 5% RH and 10°C.

- The addition of Tween 20 helped uptake but not significantly. Most of these problems of uptake were reduced if the NAA was applied in solutions buffered to pH 4 with DL-lactic acid and the accelerator adjuvant Genapol C-100 (0.2-2.0gl-1) was added.

- This combination improved uptake at low temperatures and in hard water or at low humidities.

- NAA is destroyed by UV light and sprays are best applied in the late afternoon or early evening.

- NAAm is slightly less dependent upon ideal weather conditions than NAA; the latter can only be used with confidence where stable climatic conditions during blossoming prevail.

- However, even when using NAAm seasonal variability in response is common and varieties differ in their sensitivity to the sprays.

- When applied late, NAAm often reduces the speed of growth of the persisting apple fruitlets and may have no beneficial effects on fruit size at harvest.

- NAAm is usually applied soon after flowering, whilst NAA is applied a little later, although it will also thin if used during flowering (Jones et al., 1989).

- Concentrations of NAA are usually up to 20 ppm whilst those for NAAm are up to 100 ppm.

- The liquid formulation of NAAm is more active than the powder formulation.
Carbaryl
Little is known concerning the mode of action of carbaryl in thinning fruitlets.
- However, one suggestion is that the sprays inhibit or slow down seed development in the fruit and that this in turn reduces the production and diffusion of auxins from the fruits.
- The fact that carbaryl thins more severely if applied during low light conditions may support this hypothesis.
- The product is a weak thinner but applications at the time of flowering may stimulate mild skin russetting in some situations.
- The thinning action of carbaryl increases with spray concentration up to approximately 750 ppm and this is the dose used in many countries.
- Overdosing and overthinning is unlikely to occur when using carbaryl.
- The product is very toxic to bees and sprays to flowers that are being worked by bees should be avoided (Helson et al., 1994), although formulations providing more safety to bees (e.g. Sevin XLR) have been used (Nichols, 1996).
- Note that carbaryl is not approved for use on apples in the UK and that it is likely to be withdrawn in Europe.

Ethylene releasing chemicals
Treatments with ethephon, a chemical that releases ethylene when sprayed onto plants, are known to stimulate abscission of flowers and fruitlets. Ethephon (Ethrel C) influences the production and transport of the auxins (which normally inhibit abscission) and also increases the evolution of ethylene gas by the fruits and leaves.
- The problem with the use of ethephon as a flower or fruitlet thinner is the extreme variability of response recorded in many experiments.
- Extensive research in Tasmania has shown that both spray concentration and timing of the sprays were an important cause of variation in response (Jones et al., 1983; Koen and Jones, 1985) see Further reading [hyperlink].
- The same team also showed that the thinning response to ethephon sprays was very closely associated with increasing temperatures (Jones and Koen, 1985).

Photoperiodic chemicals
Research in the USA has shown that sprays at low concentrations of the herbicide terbacil (a photosynthetic inhibitor) have had beneficial thinning effects (Byers et al., 1990a; 1990b).
- The theory is that the temporary check to photosynthesis triggers a chain of events leading to fruitlet abscission.
- Although proved effective in USA trials, this strategy is a high risk one.
- Extensive leaf damage and abscission has occurred in some trials testing terbacil and other similar products.

Cytokinins (benzyl adenine – BA)
Sprays of the synthetic cytokinin benzyl adenine at or around the 7-12 mm fruitlet diameter stage have been shown to induce fruitlet abscission and/or increase final size of apple fruits at harvest (Bound et al., 1991; Bound et al., 1993; Greene and Auto, 1989; Greene and Auto, 1994).
- In Australian trials, and when applied at the correct timing, BA has proved more consistent in thinning than carbaryl.
- Moreover, unlike carbaryl BA is not toxic to important predatory mites species used for biological control and the toxicity of BA to mammalian and arthropod species is low (Thistlededdar and Elving, 1992).
- However, the responses are temperature dependent and 18°C or more is needed if thinning is to be consistent (Greene and Auto, 1994; Bound et al., 1997).

The thinning mode of action of the BA sprays is not understood.
- One theory was that the sprays promoted the growth of bourse shoots, which in turn competed with the adjacent fruitlets for minerals and/or assimilates, causing the fruitlets to drop off.
- However, studies at East Malling showed no significant stimulation of bourse shoot growth following BA sprays.
- Trials at East Malling did suggest that BA sprays thinned fruitlets quite effectively if applied following a spray of a blossom thinner such as ATS.
- One possibility is that the blossom thinner reduces the seed numbers in the fruitlets, making them more vulnerable to the later BA sprays.
- Further research is needed to understand how BA brings about its thinning action and how environmental and other factors influence its uptake.
- This understanding will be necessary if consistent thinning responses to the chemical are to be achieved in the future in UK orchards.

In several trials, BA treatments have improved the size of harvested fruits but caused no reduction in final fruit numbers per tree (Greene et al., 1992; McArthur et al., 1992).
- It has been suggested that this is due to a direct effect of the sprays on fruitlet cell division.
- USA trials showed BA sprays to induce cortical cell division and to increase cell layer formation in ‘Empire’ apples (Wesner et al., 1995).
- However, further work is needed to support this theory and explain why the effect is not consistent from season to season.

Other compounds with cytokinin activity may also prove useful as fruitlet thinners for apples.
- Both forchlorfenuron (CPPU) (Greene, 1993) and thidiazuron (THI) (Greene, 1995) have shown some thinning activity in trials.

Modelling crop loading and aids to decision making in thinning
It is recognised throughout the world that one of the most difficult and often most expensive decisions for commercial apple growers is whether or not to thin. Many factors must influence the decision including tree and variety characteristics, previous cropping history and the weather conditions before, during and after flowering.

Researchers in the USA have developed decision support systems (computer models) that take account of a multitude of climatic, cultural and application conditions to make recommendations on the use of chemical thinners.
- One such system THIN-IT developed in Washington State, produces a range of recommendations and is mainly appropriate for the dry and climatic conditions of the Pacific North West of the USA (Williams and Wright, 1991).
- A slightly more sophisticated model has been developed in Pennsylvania and is incorporated into a larger suite of models distributed as the Penn State Apple Orchard Consultant (Crawsler et al., 1992).
- Unfortunately, although this system is more appropriate for maritime climates similar to the UK, it has little immediate value to the UK grower, as it focuses on use of products either not approved in the UK (NAA and NAD) or on products about to be withdrawn (Carbaryl). Another USA computer programme, focused on thinning apples has been developed for growers in New York State (Sloven, 1992).

Researchers in Tasmania, Australia (Jones et al., 1987) have also developed computer models to aid growers in making decisions on apple thinning.
- The basis of the model is a mathematical model of optimum crop loading.
Data from experiments over a twenty-year period have been used in this model.

Factors, such as the scion variety, the rootstock, the thinning chemicals to be used, the age and size of tree and the fruit size required, are all taken into account.

In addition, the model takes account of what are known as modifying factors; these are last year's crop, rate of shoot growth and pruning severity.

The aims to deliver a best practice for Tasmanian orchardist.

Unfortunately, this model, like those developed in the USA is not appropriate for UK use on account of the climatic differences and the reliance on use of ethephon as a thinning chemical.

A full explanation of the Tasmanian model is given in a recent review paper (Jones et al., 2000).

No models have yet been developed suited to UK conditions and utilising thinning strategies available to the UK grower.

Improving fruitlet growth and quality

Although flower or fruitlet thinning represents the most important strategy for improving final fruit size and quality, supplementary factors which influence fruit size and quality should also be considered.

If apple orchards are to be profitable it is essential that a high proportion of the harvested yields (>80%) should be of suitable size, appearance and quality to command the highest available market returns. It is therefore important to optimise all management inputs to ensure the best fruit size and quality at harvest and through storage. To achieve these objectives:

- Ensure that fruitlets set with adequate numbers of seeds.
- Encourage cell division and expansion in fruitlets.
- Prune and train trees so as to optimise exposure of the fruits to light.
- Maintain adequate and balanced supplies of water and nutrients to trees.
- Avoid use of crop protection or other sprays that may damage the skin finish of the fruits.
- Apply sprays of gibberellins to improve skin finish.

Ensure that fruitlets set with adequate numbers of seeds

Fruits with few seeds may, in some seasons, be slightly misshapen or smaller and it is always recommended policy to ensure setting of fruits with many seeds. Ensure that apple fruits are set with adequate seed numbers by:

- The planting of suitable pollinating varieties in adequate numbers within the orchard.
- The introduction of sufficient bee hives, each with 'strong' colonies of bees.
- The creation of suitable shelter within the orchard to aid bee activity and pollen germination and growth.
- Ensuring good pollination with the variety Braeburn so as to increase fruit seed numbers and help uptake of calcium into this bitter pit sensitive variety.

Encourage cell division and expansion in fruitlets by optimising orchard management

Apple fruits grow by cell division and cell expansion. Most cell division occurs in the first 3–4 weeks following fruit set and by 7 weeks cell division has almost finished. Thereafter, fruits grow by the cells expanding.

The best large fruits, in terms of texture and storage potential are those with many cells rather than fewer larger cells.

Increasing the size of fruits by applications of irrigation and nitrogen, so as to increase cell expansion, may produce fruits of poor texture, which store poorly.

The principal factors influencing cell division in young fruitlets are:

- Initial flower quality
- Crop loading
- Climatic conditions in the first month after fruit set.

Initial flower quality

Poor 'quality' flowers usually result in poor quality fruits, which may be smaller than average and of poor texture.

- The production of flowers of high 'quality' is aided by:
  - Optimising crop loads in the previous season.
  - Maintaining a good balance of new shoot growth and flower production by appropriate pruning/training, nutrition and irrigation.
  - Ensuring that the sites of flower production (e.g. the spurs) are well exposed to light.
  - Ensuring that the concentrations of gibberellins in sprays applied to aid skin finish, are kept to a minimum.
  - Biennial bearing varieties often produce poorer quality flowers, as well as fewer flowers in their "off" year.

Crop loading

Crop loading can have a significant effect on fruit size and quality.

- Early thinning of apples by blossom thinning or very early fruitlet thinning will reduce the competition within the tree for assimilates (carbohydrates produced by photosynthesis) and improve cell division in the persisting fruitlets.
- Early thinning will improve fruit size and firmness and advance ripening.
Photosynthesis and carbon supply to the fruitlets

A number of factors, other than crop loading are known to influence cell division and expansion. These are:

- Such conditions will also aid the development of bourse and extension shoot leaves which will begin to contribute to the vital carbohydrates produced by photosynthesis which fuel the growth of young fruitlets.
- Endeavour to increase temperatures in orchards during the first six weeks following fruit set, so as to maximise cell division in the young apple fruits.

Prune and train trees so as to optimise exposure of fruits to light

Use of training systems which expose fruitlets to the full sunlight, such as Tatura or other trellis systems will also improve cell division.

- Prune and train trees so as to optimise exposure of fruits to light and achieve good colour development
- In UK conditions it is essential to ensure that young developing fruitlets and the leaf canopy which supports the expansion and growth are well exposed to sunlight. This is achieved by judicious use of pruning and training techniques.

Irrespective of the scion variety, the rootstock or the system of pruning and training chosen, it is vital in all instances to ensure good light penetration into the canopy and good exposure of the fruits to light throughout the growing season and especially in the weeks prior to ripening.

- Prune and train trees so as to maintain a balance of flowering spurs and new extension shoot growth.
- Stimulate growth on trees producing too little extension growth by making a few severe cuts back to vegetative buds in positions where new shoots/branches are desired.
- On trees with excessive shoot growth, reduce this by training shoots to the horizontal (or lower)
- Where summer shoot growth results in shading of fruitlets and poor fruit colour at harvest use summer pruning techniques to open up the tree canopy and expose the developing fruitlets to better light conditions.
- The need for summer pruning indicates that tree vigour is too strong.
- Review pruning and tree management and consider ways to reduce growth.
- On varieties such as Gala, prune so as to encourage the production of medium strong wood and reduce the production of weak ‘wispy’ shoots, which give rise to small fruits.

Maintain adequate and balanced tree nutrition and water supply

If fruitlets are to expand and develop into high quality large fruits at the time of harvest it is essential to maintain adequate supplies of water and nutrients to the tree throughout the growing season.

- Ensure that the trees are supplied with adequate water and nutrients so as to maintain the cell expansion and growth of apple fruitlets.
- Monitor water requirements regularly, using calculations of evapotranspiration or other equipment marketed to measure soil water levels.
- Check soil and leaf nutrient levels regularly and adjust nutrition accordingly.

Avoid use of crop protection or other chemical sprays which may cause damage to the skin of fruitlets (russetting)

Use of certain pesticides or other sprays may, on occasions, result in damage to the fruit skin and loss of quality.

- Adhere to label recommendations for pesticides, concerning rates, water volumes, compatible tank mixes and weather conditions, so as to avoid phytotoxicity damage and loss of fruit quality due to russetting.
- Avoid spraying within two days of a sudden change in weather patterns, particularly a rise in temperature, as the fruitlet will be very sensitive to any spray damage.
- It is known that sulphur and high rates of copper will cause damage to fruitlets of Cox.
- Full rate sprays of dithianon can cause russetting to Gala when applied at the fruitlet stage.
- Damage can be avoided by reducing spray rates and not spraying in stressful conditions.
- The addition of GA_{4+7} to sprays (see below) during this period can also reduce russetting.

Apply gibberellin sprays to improve final skin finish of fruits

Sprays of gibberellin (e.g. Regulex, Novagib) can improve the skin finish of varieties such as Cox at harvest time. GA_{4+7} is approved for use in the UK and trials have demonstrated that small but significant increases in % Class 1 fruit can be achieved.

- As fruitlets can be sensitive to russetting over a long period, a programme of sprays is regarded as better practice than just one or two applications.
- On varieties such as Cox and Discovery apply sprays of GA_{4+7} (e.g. Regulex or Novagib) at label recommendations (4 times at 5-10 ppm, at 10 day intervals commencing at first open flower) so as to improve skin finish at the time of harvest.

Fruitlet growth

After fruit set, the growth of the persisting fruitlets is brought about by a combination of cell division and cell expansion. It is generally accepted that the majority of cell division takes place in the first 6 weeks ceases within 4 weeks after pollination and cell expansion continues throughout to harvest.

A number of factors, other than crop loading are known to influence cell division and expansion. These are:

- Photosynthesis and carbon supply to the fruitlets as influenced by temperature and light.
- Production and movement within the tree of natural plant hormones.
- Tree health and nutrition.

Photosynthesis and carbon supply to the fruitlets
The demand for assimilates (carbohydrates produced by photosynthesis) increases rapidly following bloom, peaking at about 4-6 weeks after full bloom and then remaining fairly stable through until harvest.

- There are two periods of potential limitation of carbon supply; one about 2-4 weeks after blooming and the other in the last few weeks prior to harvest.

Production and movement within the tree of natural plant hormones

Fertilised ovules (i.e. developing seeds) produce hormones.

- Gibberellins are found in apple seeds and have an implicated in the growth of fruits.
- Gibberellins are also essential for the development of apples with good skin finish and freedom from russet.

Tree health

The general health of trees is important and trees suffering significantly damaging pests or diseases will inevitably produce fruits of smaller size and quality at harvest.

- Most of the apple trees grown in the UK are free from the viruses and phytoplasmas that might influence fruit size and quality at harvest.
- However, care should be taken to ensure that any variety or clone used is as free as possible from these diseases.
- The disorder known as chat fruit reduces fruit size on some varieties, such as Lord Lambourne, and it is important that growers ensure that their young trees are free of this problem.

Ensure that fruitlets set with adequate numbers of seeds

Research conducted in New Zealand has shown that enhancing the pollination of the variety Braeburn not only increases fruit set but it also increases seed numbers and the calcium content of the harvested fruits (Volz et al., 1996).

- Further research in New Zealand showed that with increasing distance from pollinator trees, Braeburn fruits had lower seed numbers, increased poor shape, lower calcium concentrations and increased incidence of bitter pit and lenticel blotch (Brookfield et al., 1996).
- Research conducted in Russia many years ago suggested that choice of pollinators could affect the size, shape and quality of the fruits produced.
- However, attempts both at East Malling and Long Ashton to substantiate this effect (known as metaxenia) have proved unsuccessful.
- The only likely effects of pollinator choice on fruit size or shape is possibly via their effects on seed numbers.
- Ensure that apples set with adequate numbers of seeds as this will improve fruit size and shape and also increase calcium uptake on varieties such as Braeburn.

Optimise crop loading by judicious thinning of flowers and/or fruitlets

It is important that reducing crop loads not only improves the final fruit size of apples.

- At lower crop loads, the apples are often of improved quality; they ripen earlier, are sweeter, often firmer and have higher levels of dry matter.
- Work conducted at East Malling many years ago showed the effects on fruit size, quality and storage potential of thinning the variety Cox's Orange Pippin (Sharples, 1989).
- More recent work on the same variety (Johnson, 1995) has shown that the ripening maturity of fruits is advanced by thinning treatments conducted at 5 days after full bloom but not by similar thinning treatments carried out 27 or 39 days after full bloom.
- Advances in maturity, as judged by internal ethylene concentration, were as much as 16 days.
- Similar effects of thinning on fruit quality at harvest time have also recently been demonstrated for Braeburn apples growing in Spain (Kelner et al., 1999).

Cell division

Thinning apples can significantly increase cell division in the fruits remaining on the tree.

- However, only early thinning, either of flower buds or flowers, can achieve this objective.
- Delaying thinning to the 12 mm fruitlet stage or later will often have only minimal effects on cell division in the persisting fruits, although it will result in increased cell expansion.
- This is explained by the fact that cell division in fruits such as Cox is completed by about 6 or 7 weeks after full bloom (Denne, 1990).
- Removal of excess flower buds in the winter months will also have benefits to cell division in the fruits forming on the remaining flower buds.

Fruit firmness

More recently, studies conducted at East Malling on the apple variety 'Cox's Orange Pippin' (Johnson, 1992 and 1994) showed that the firmness of fruits at harvest was increased significantly if the trees were thinned, even when fruit size was increased by the thinning.

- Subsequent studies showed that thinning to single fruits/cluster in the period between 5 and 15 days after full bloom gave the best results.
- Thinning to similar levels at 25 days after full bloom gave no increase in firmness at harvest, but later thinning did improve harvest firmness.
- All the recorded increases in fruit firmness were associated with increases in the percentage dry matter in the fruits.
- The increases in harvest firmness were maintained after storage of the fruits in CA conditions (2% O₂ and ≤1% CO₂) but not in CA with lower O₂ levels or in air storage.
- In the low O₂ regime (1.25%) the enhanced softening is thought to have been attributable to increased sensitivity to core flush and senescent breakdown, which may have been related to the higher K and lower Ca status of these fruits.

Early thinning of apples by blossom thinning or very early fruitlet thinning will reduce the competition within the tree for assimilates and improve cell division in the persisting fruitlets.

- Early thinning will improve fruit size and firmness and advance ripening.
- However, in some situations early thinned fruits may be more sensitive to storage disorders, such as senescent breakdown and core flush.
Climatic conditions in the first month after fruit set

Warm temperatures in the 4 to 6 weeks after fruit set will have a very beneficial effect in encouraging cell division in the young developing fruits. Such conditions will also aid the development of bourse and extension shoot leaves which will begin to contribute to the vital carbohydrates produced by photosynthesis which fuel the growth of young fruitlets.

- Any improvement of orchard site conditions, such that temperatures are raised slightly, may have a significant beneficial effect on cell division in the fruits.
- Aim to increase temperatures in their orchards during the first six weeks following fruit set, so as to maximise cell division in the young apple fruits.
- Choice of training systems has also been shown to influence fruit size, possibly via their effects on flower bud quality and cell division in the young fruitlets.
- Training systems which maximise light exposure of the canopy, such as Tatura or other canopy systems frequently improve cell division and produce fruits of larger than average size.

Prune and train trees so as to optimise exposure of fruits to light and achieve good colour development

Prune and train trees so as to maintain a balance of flowering spurs and new extension shoot growth.

- Lack of new growth, as may be experienced with trees of dessert varieties on M27 rootstock, leads to high yield productivity but poor fruit size and grade-outs.
- Stimulate growth on trees producing too little extension growth by making cuts back to vegetative buds in positions where new shoots/branches are desired and remove weak shoots and spurs.
- The ends of weak fruiting branches should be tipped to an up and facing bud especially in varieties that crop on one year wood.
- On trees with excessive shoot growth, reduce this by training shoots to the horizontal (or lower).
- Where summer shoot growth results in shading of fruitlets and poor fruit colour at harvest use summer pruning techniques to open up the tree canopy and expose the developing fruitlets to better light conditions.

Observations on Gala trees growing in New Zealand suggest that large fruits are only produced on large calibre fruiting wood (Wilton, 1997 see Further reading [hyperlink]).

- Fruit bud quality and the strength of carrying the buds is believed to be more important than the age of wood.
- Buds formed on one-year-shoots (axillary flower buds) can set and size good fruits, if they are carried on wood of 10 mm or more in diameter.
- The same author believes that bourse shoots, which terminate growth early in the season, are essential for maximising fruit growth potential.
- Weak wood should be shortened to two or three buds.
- This weak wood is usually the source of small fruits, especially if it is located in shaded parts of the tree canopy.

Maintain adequate and balanced tree nutrition and water supply

If fruitlets are to expand and develop into high quality large fruits at the time of harvest it is essential to maintain adequate supplies of water and nutrients to the tree throughout the growing season.

**Irrigation**

The influence of different amounts and timings of water supply to the growth and final size and quality of apple fruits has been studied in many regions of the world.

- Unfortunately, the results are often variable, and are probably influenced greatly by local climatic conditions and soil types.
- Reduced supply of water to trees growing in areas experiencing hot dry summers, results, as expected in a higher proportion of smaller fruits at harvest time.
- As might be expected, application of increasing amounts of irrigation result in faster growth rates for fruitlets and larger fruit size at harvest.
- However, several reports show irrigation of fruits also reduces fruit firmness and lowers the soluble solids content, in some but not all years (Bonany and Camps, 1998).

In most UK orchards and in most seasons it is not a problem in UK climatic conditions to maintain adequate supplies of water and nutrients to the tree throughout the growing season.

- However, where trees are grown on shallow or sandy/gravel soils supplementary irrigation will be a necessity in most seasons.
- This is best provided using a trickle irrigation system, which can supply water regularly and in low controlled amounts.

Water needs are estimated using calculations of water deficits based on evapotranspiration or are measured using various other systems (neutron probes, tensiometers etc.).

- Research conducted on Braeburn trees has shown that withholding necessary irrigation water early in the season (up to 104 days after full bloom) reduced shoot growth and mean final fruit weight, although rates of photosynthesis did not appear to be affected.
- In contrast, withholding water later in the season (i.e. 104 to 194 days after full bloom) had no influence on mean fruit size (Kili et al., 1996a).
- The same authors (Kili et al., 1996b) noted that withholding water late in the season increased total soluble solids, soluble sugars (fructose, sucrose and sorbitol), flesh firmness and red skin colour intensity.
- This late withholding of water, therefore, may have merits in certain situations. However, care must be exercised when using these Regulated Deficit Irrigation (RDI) systems of management.

Research in the USA (Ebel et al., 1993) has shown that whilst RDI systems produced apples with higher soluble solids, the fruit sizes at harvest were reduced.

- If fruit size is not to be reduced deficits should only be imposed late in the growing season.

Recent work in New Zealand showed that irrigating Braeburn trees on MM106 rootstock improved the concentrations of calcium in the fruits at harvest (Mils et al., 1994).

- Fruits from non-irrigated trees developed sugars slightly earlier than fruits from irrigated trees.

**Nutrition**

Nutrient deficiency is unlikely to influence fruitlet growth in most conventional orchards, which are fertilised to established recommendations. However, nitrogen and potassium deficiency in organic orchards is likely to be a problem.

- Ensure that the trees are supplied with adequate water and nutrients so as to maintain the cell expansion and growth of apple fruitlets.
- Monitor water requirements regularly, using calculations of evapotranspiration or other equipment marketed to measure soil water levels.
- Check soil and leaf nutrient levels regularly and adjust nutrition accordingly.
Avoid use of crop protection or other chemical sprays which may cause damage to the skin of fruitlets (russetting)

Most pesticides currently approved for use with UK apples will cause no problems of skin russetting, if applied according to the label recommendations.

- However, growers should take care when using tank mixes of several different products.
- Only use the tank mixes recommended by the manufacturers.
- Occasionally, applications of two or more products may cause russetting.
- This is often the result of incompatibility of the mixtures and/or enhanced uptake due to the combination of several surfactants.
- Adhere to label recommendations for pesticides, concerning rates, water volumes, compatible tank mixes and weather conditions, so as to avoid phytotoxicity damage and loss of fruit quality due to russetting.

Apply gibberellin sprays to improve final skin finish of fruits

Trials conducted at HRI-East Malling in the early 1980s showed the benefits of applications of GA4 + 7 (Regulax) on the skin finish of Cox, Discovery and Golden Delicious (Taylor et al., 1985).

- Four sprays at low concentrations (2.5-10 ppm), commencing at first open flower and applied at 10-day intervals, significantly improved the fruit grade out by reducing the russetting on fruits.
- Only the sprays applied at the highest concentration (10 ppm) had any significant effect on return bloom the following season.
- When pure formulations of GA4 and GA7 were compared the former produced the best response, in terms of russet prevention and also had the least effects upon return bloom.

Trials abroad have shown that sprays of Promalin (16 ppm of a mixture of GA4 + 7 and benzyl adenine) can reduce russetting on varieties such as Golden Delicious (Eccher and Meff, 1996).

- Promalin is approved for use on some varieties of apple, especially in the USA.
- These sprays improve fruit shape by increasing the length:diameter ratio of varieties such as Red Delicious (Curray and Williams, 1983; Unrath, 1978) and may also increase fruit weight (Unrath, 1978).
- Applications of Promalin at 25 ppm at full bloom give the most beneficial effects.
- Trials with Promalin on Cox, conducted at Long Ashton in the late 1970s, showed no effects on fruit length:diameter ratios (Child et al., 1985).
- On varieties such as Cox and Discovery apply sprays of gibberellic acid (e.g. Berelix) at label recommendations (4 times at 5-10 ppm, at 10 day intervals commencing at first open flower) so as to improve skin finish at the time of harvest.

The physiology of fruitlet growth

After fruit set, the growth of the persisting fruitlets is brought about by a combination of cell division and cell expansion.

- Research undertaken many years ago showed that the majority of cell division ceases within 4 weeks of pollination (Bain and Robertson, 1951), whereas cell expansion continues throughout the growth period of the fruit.
- In this Australian research conducted on Granny Smith apples, final differences in fruit size were associated more with cell number than with cell size.
- Even earlier research on the variety Bramley’s Seedling similarly showed cell division to cease only a few weeks after fruit set (Tetley, 1930 and 1931).
- Research in New Zealand on the variety Cox showed that fruit weight increased slowly for the first few days following pollination then increased exponentially at a very rapid rate for three weeks and, thereafter, increased at diminishing rates (Denne, 1960).
- Cell division was very rapid in the three week phase of exponential growth and then declined but some cell division occurred until 6 or 7 weeks after pollination.
- Cell expansion was also very rapid until 7 weeks after pollination but then occurred at diminishing rates until harvest.
- Studies on the variety Cox in the early 1960s showed that differences in cell size at harvest were not an important factor influencing final fruit size (Skene et al., 1984).
- The indications were that fruit size was more influenced by cell numbers and that few new cells were produced after the fruitlets had reached approximately 18 mm in diameter.
- The main bulk of any apple fruit, which is thought to develop from the receptacle in the flower, consists of a parenchymatous tissue forming the flesh, of which the cortex constitutes the greatest percentage by volume. The cells of the cortex are of spongy tissue, large, thin-walled with a thin lining of cytoplasm and a large vacuole.
- A number of factors, other than crop loading are known to influence cell division and expansion. These are:
  - Photosynthesis and carbon supply to the fruitlets as influenced by temperature and light.
  - Production and movement within the tree of natural plant hormones.
  - Tree health.

Photosynthesis and carbon supply to the fruitlets

Work conducted in the USA, using equipment capable of measuring the light interception of the various types of leaves and the gas exchange associated with a whole apple tree, has enabled scientists to work out the photosynthetic potential and the tree’s assimilate needs to sustain a crop load at various times during the season (Lakeso et al., 1996).

- This work shows that the demand for assimilates increases rapidly following bloom, peaking at about 4-6 weeks after full bloom.
- Thereafter, it remains fairly stable through until harvest.
- Comparing this demand with the tree’s potential to supply showed that the carbon production by the apple tree leaf canopy cannot support all of the fruits, which potentially could set, for more than a week or more after bloom.
- The work shows that, during the season there are two periods of potential limitation of carbon supply: one about 2-4 weeks after blooming and the other in the last few weeks prior to harvest.

This identification of a critical period for assimilate supply is supported by other recently published research.

- Researchers in Michigan showed that applications, 15 to 30 days after full bloom of chemicals known to limit photosynthesis temporarily (e.g. terbacl) caused fruitlet abscission (Piore et al., 1996).
Research at East Malling has shown that shading of apple trees also reduces photosynthesis and may cause reductions in fruit size, as well as reducing flowering and fruit set (Jackson and Palmer, 1977).

- However the shading needed to significantly reduce fruit size was 63% or more.
- Severe shade (only 10% of full sunlight) reduced fruit size by 30%.
- Further work by the same team (Jackson et al., 1977) showed that the shading reduced fruit size by reducing both cell numbers and individual sizes within fruits.
- Shading also reduced fruit colour, russetting, cracking, and the dry matter and starch per unit weight.
- Research in Japan has shown that glucose, fructose and sucrose contents of apple fruits are all decreased by shading.

It is argued that the high productivity of compact trees, such as those produced on dwarfing rootstocks, is attributable to a high level of light interception within the tree canopy; this in turn improves photosynthetic capacity (Robinson and Lulko, 1991).

- Training systems also influence light interception and hence photosynthesis and fruit size.
- German research has shown that trees trained to a Y trellis system bore more fruits and larger fruits than trees grown on spindles (Chen et al., 1996).
- Fruits from the Y trellis system were also higher in dry matter, total soluble solids, starch, glucose, fructose, sorbitol and total non-structural carbohydrates.

Production and movement within the tree of natural plant hormones

- Gibberellins have been strongly implicated in the growth of fruits. Many gibberellins have been identified in the seeds of apple fruits (Hedden et al., 1993). Soon after anthesis (first opening of the flower), high concentrations of the active gibberellins A\(_1\), A\(_3\), A\(_4\), and A\(_7\) are found in the apple seeds.
- These are believed to provide an important stimulus to fruitlet growth (Hedden and Hoad, 1985).
- Gibberellins are also essential for the development of apples with good skin finish and freedom from russet.
- Sprays of GA\(_4\) or GA\(_7\) are applied to improve skin finish.
- Trials in the USA indicate that gibberellins are also implicated in determining the shape of fruits. Fruits of the variety Red Delicious which are high in gibberellins at or just after flowering develop a more angular shape at their basal end.

A review of recent studies focused on the importance of gibberellins in fruit set and development has been produced by García-Martínez (1997).

Initiation and development of sufficient high quality flowers by the apple tree

Introduction

It is essential that apple trees produce sufficient flowers to set an optimum crop of fruit in relation to the size of the trees. It is also vital that these flowers are of sufficient quality to set fruits reliably and to produce large fruits of good texture and storage potential.

On young newly-planted trees the objective is to induce quality flowers on the trees in the second and third years after planting i.e. to improve their floral precocity. If orchards are to break-even rapidly and move towards profitability on the investment, cropping early in the orchard's life is essential.

On mature trees, lack of abundance of flowering is a relatively rare problem and usually only occurs with varieties that are prone to biennial bearing. Fortunately, most of the traditional varieties suffering from this problem (e.g., Miller's Seedling, Laxton's Superb) are no longer grown commercially, but Bilbar can become strongly biennial in its cropping. The varieties Cox and Braeburn are weakly biennial. However, flower quality is often a limiting factor in fruit set and retention on mature trees.

Occasionally, excessive flowering and inadequate new extension growth may be a problem with some varieties grown on dwarfing rootstocks such as M27 and M9 on replant soils. Here the objective must be to reduce the abundance of floral spurs and increase shoot growth, so as to bring the trees back into a more optimal balance of fruit production with shoot growth.

Improving the initiation and development of high quality flowers by the apple tree

Flower initiation occurs early in the summer of the season prior to flowering and, during that season, many of the flower parts are formed. However, the final stages, which involve the formation of the pollen sacs and the ovules, do not occur until shortly before bloom in the subsequent spring. High quality flowers are essential if fruit set is to be achieved in the often less than ideal weather conditions at flowering time in UK orchards. Flower quality influences whether fruits are retained on trees throughout the season and also their size and quality at harvest.

Adequate floral abundance and good flower quality are essential considerations for both mature and young, immature trees. Flowering and fruiting on young apple trees in the second and third year is particularly vital if the investment in the orchard is to be economically viable.

The importance of good flower quality

Flowers on apple trees differ in their potential to set and retain fruits and these differences are usually referred to as differences in flower quality. Flower quality is the ability of a flower to set and carry a fruit. The most common measurement of flower quality is the Effective Pollination Period or EPP.

Types of flower buds

Spur buds: Formed on spurs and short terminal shoots. These begin their initiation shortly after fruit set in the preceding season.

Auxiliary buds: Formed in the lower (basal) leaf axils on extension shoots later in the season than spur buds, usually as shoot growth slows down in mid to late summer.

The aim must be to encourage the rapid production of high quality flowers on the spurs and short terminal shoots of young trees. Only with a few varieties, such as Gala and its sports, can auxiliary flowers be relied upon to contribute significantly to cropping on young trees. Even with Gala, auxiliary flowers are only useful if they are produced on strong wood of approximately 10 mm diameter.
Factors influencing flower quality

Anything that reduces the production of resources by the tree or diverts them away from the developing flower buds will reduce their quality. An imbalance of hormone levels in the tree will also affect flower bud development. The main factors influencing flower quality are:

- **Crop load** (too many fruits on the tree): Reduce flower bud numbers in the following year especially in varieties with a tendency to biennial cropping. Thin as early as possible to the correct crop load.
- **Too much vigour** (length of shoots and numbers of shoots) will create an imbalance in the tree and reduce the quality of flower buds: Adopt practices to reduce vigour.
- **Lack of light and shading** will significantly reduce flower bud quality: Prune to improve light penetration into the canopy.
- **Poor leaf quality; poor nutrition and disease** (especially mildew) will impact directly on flower bud quality: Mildew should be controlled all the way through the season to prevent infection in developing buds which will carry over to the next season. Nutrient levels should be checked by visual and analytical techniques. It is particularly important to avoid excess nitrogen levels and maintain adequate phosphorus and trace elements to ensure good flower bud development.

Improving flowering on young newly-planted apple trees

If apple orchards are to prove profitable it is important that they begin cropping as soon as possible after planting (i.e. exhibit good yield precocity) and then rapidly build up cropping to high and consistent yield efficiencies in the succeeding years.

The yields in the first few years of the orchard’s life are vital if the investment is to prove viable. Investment appraisals using techniques of Discounted Cash Flows or Net Present Values highlight the importance of yields achieved in the first five years of an orchard’s life.

To achieve these yields in the first few years following planting it is essential that the trees produce adequate numbers of flowers and that these flowers are of sufficient quality to set and retain fruits through until harvest. This precocious cropping must not, however, be at the expense of the trees continuing to grow and fill their allotted space within the orchard. Balanced growth and cropping should be the aim in these early years following planting, as much as in the subsequent years.

When planning and planting young trees the importance and influence of the following should be considered:

- **Well-feathered trees**
- **Choice of rootstock and/or interstock**
- **Tree age/size and transplanting check**
- **Soil and foliar nutrition**
- **Pruning and training techniques**
- **Plant growth regulator treatments**

The importance of planting well-feathered trees

Plant well-feathered trees with healthy, non-desiccated roots. Tree quality at the time of planting has a significant influence on how well the young trees establish and how quickly they begin to flower and fruit.

The onset of flowering is advanced and the abundance and quality of flowers improved if well-feathered trees are planted in good fertile soils.

Trees with 6 to 8 strong well-spaced feathers with wide branch angles should be chosen.

It is also important that these relatively large trees receive good water, nutrition and soil management to minimise the transplanting check to growth. Excessive transplanting check to growth will cause tree stunting and may lead to the production of branches with bare wood.

- **Various nursery techniques** are used to improve tree quality
- **Where available choose trees guaranteed virus-free and true-to-type**: Healthy trees establish more quickly and crop more abundantly.

**Choose the most appropriate rootstock for the site/soil conditions, the chosen scion variety and the planned system of management**. Irrespective of the vigour of tree desired by the apple grower, always choose the rootstock, or rootstock/interstock combination which is likely to induce precocious cropping. Most dwarfing rootstocks (M9 and its clones e.g. Pajam 1 and Pajam 2, M27, P22 etc.) improve precocity of cropping. Unless soil conditions are excellent avoid use of very vigorous rootstocks such as M27 and P22. Amongst the more vigorous rootstocks MM.106 and M.116 both induce good floral precocity in scions and are well suited to use in cider orchards. Use of dwarfing rootstocks as interstocks also improves floral precocity of scions.

Post planting management

Trees planted in the autumn into deep, highly fertile soils with adequate supplies of water throughout the subsequent season should establish very well and make abundant shoot growth. When planting small or poorly feathered trees this response is desirable. However, where larger than average trees are planted, such conditions could result in excessive shoot growth and the production of fewer, poorer quality flowers in the second season following planting. Tree management after planting should aim to achieve balanced growth and precocious cropping.

Take steps to improve flower quality (i.e. ability to set fruits) on young trees. By being aware of the limitations on fruit set associated with poor flower quality on very young trees, it is possible to improve the situation by:

- **Applying appropriate fertilisers**, as determined by soil and leaf analysis, preferably through a fertigation system
- **Bending branches down on upright varieties, or varieties with poor fruiting habit**, can improve flower quality and subsequent fruit set. This is not necessary in very precocious varieties.

Ensure good tree establishment and avoid bare wood developing by:

- **Planting in good conditions**, preferably before Christmas. Delayed planting can result in a planting check which is generally undesirable although in some circumstances may be beneficial e.g. stringfellowing.
- **Providing adequate water and nutrients** (both to the roots and by foliar feeding).

Growers should obtain analyses of the soil mineral and organic matter contents prior to tree planting. Based on these analyses and the current recommendations concerning optimum levels (R209) any necessary base dressings should be applied.
Supplementary nutrition of trees in their first or second years following planting have been shown to improve crop levels in intensive plantings of 2000+ trees per hectare. Supplementary irrigation should be applied, preferably using trickle systems, when soil moisture deficits reach 50 mm. Prevent stress to the trees (e.g. wind desiccation).

Prune and train trees so as to establish ideal balance of growth and flowering:

- Remove excess feathers, especially those with strong upright growth and poor branch angles. This will help produce better leaf and flower quality on the remainder. Aim for 6-8 good feathers. Remove low and unwanted feathers.
- Do not tip the leader except when poor quality trees with very weak or few feathers are used. Where good, well feathered trees are planted, leaving the leader unpruned will encourage the development of weak fruiting laterals and give natural growth control of the leader which is ideal in intensive orchards.
- Tie down lateral growth towards the horizontal or below this angle on very strongly growing varieties.

Use low doses of chemical growth regulators where necessary to achieve reduced shoot growth, improved balance of growth and improved fruit set.
- Low concentration treatments with Cultar may aid flower production on young trees that are growing too vigorously.

**Improving flowering on mature apple trees**

Occasionally, insufficient flower numbers may be produced on varieties which are not usually prone to biennial bearing. This is usually the result of practices of tree management that lead to an imbalance between growth level and cropping:

- Excessive use of nitrogenous fertilisers and/or irrigation or severe pruning can all result in vigorous extension shoot growth and the production of too few flowers.
- Good tree management entails balancing the production of flowers with adequate new shoot growth.

Although, theoretically, trees should be able to produce sustained fruit production on a tree with a permanent spur system and minimal new shoot growth, many trials have shown that fruit size and quality slowly diminish on such trees.

Examples of this are trees planted on M27 rootstocks, where insufficient renewal pruning is practised. Another example is trees producing no new shoot growth following excessive applications of growth regulators.

The first pre-requisite is to have some idea of the likely numbers of flowers developing on the apple trees. This assessment may be done pre bloom by dissection or in the orchard from blossom onwards.

**Assess the correct numbers of fruit buds needed for an optimum crop**

Take into account the variety, the growth habit of the trees and the cropping history. Assume 1 to 2 flower buds will be required to produce one harvested fruit. This is, however, dependent upon scion variety, tree vigour and site conditions.

**Cox, Bramley and Discovery**

- In well managed, regularly cropping Cox orchards the average fruit set will be between 15% and 20%.
- Each fruit bud produces a cluster of 5 or 6 flowers. Therefore, assume one fruit will set from each flower cluster.
- If 100 fruits per tree are required, leave between 100 and 120 fruit buds.
- The fruit set in vigorous, shaded trees can be much lower and 2 fruit buds will be required to ensure one fruit at harvest.

**Gala, Jonagold, Egremont Russet, Braeburn, Jazz, Kanzi and Rubens**

- These varieties set more readily and also crop well on one-year wood.
- A setting level of approximately 200-250% can be achieved
- Therefore 80 buds should produce 100 fruits.

**Increasing flower numbers on mature trees**

Apple trees that are managed well should produce adequate numbers of quality flowers consistently from season to season. Where problems of insufficient flowering occur it is important to identify the cause of the problem and take the necessary remedial action. Where insufficient flowers are present it will be due to one or more of the following factors:

- Too much vegetative growth
- Lack of light in the tree canopy
- Too heavy a crop in the previous year

**Poor flowering due to excessive vegetative growth**

Where problems of excessive shoot growth and poor flowering on mature or semi-mature apple trees are experienced it is important to adapt pruning techniques in relation to the amount of fruit bud.

- Where insufficient fruit buds is the result of excessive vegetative growth pruning and tree
Growing in the spring using plant growth regulators and other spray treatments

Growers should strive to produce flowers of high quality with an effective Pollination Period (EPP) of 3 days or more. For optimum flower bud quality:

- Trees should be thinned early in the previous season to optimum crop loads.
- Fruit harvesting should not be delayed too long, as late picking may reduce flower quality on varieties such as Bramley and Braeburn.
- Maintain good tree health status by judicious use of pest and disease control measures.
- Use nitrogenous fertilisers sparingly in the spring and summer prior to harvesting so as to reduce shoot growth which competes with developing flower buds.
- Consider foliar or ground (taking into account Nitrate Vulnerable Zone restrictions) applications of nitrogen in the autumn following harvesting, but before leaf fall, to improve the quality of flowers in the subsequent spring.
- Adopt winter pruning techniques that improve light distribution through the tree but do not encourage excessive growth. This is best achieved by making a few larger cuts.
- "Summer prune" to allow adequate light into the centres of the trees.
- Bend shoots towards the horizontal or below, but this should not be carried out to excess or the optimal balance of new renewal shoot growth and flower bud production will be lost.
- Growers should take note of the average maximum temperatures in February, March and April in their Cox orchards, as these have a significant bearing on flower quality. Where temperatures are higher than desired average maxima (i.e. 10°C or higher), they are advised to intensify their efforts to secure good pollination and flower fertilisation. This can be achieved by supplementing bee populations, providing increased shelter and controlling early growth straight after petal fall using an approved growth regulator. Where temperatures are of the desired average maximum or lower, growers will need to consider implementing appropriate thinning procedures.

Delays flowering in the spring by using plant growth regulators and other spray treatments

- When pruning in the winter prune only lightly, making fewer larger cuts.
- Concentrate on branch removal to achieve correct tree shape and let more light onto cropping branches.
- Delay leader pruning until the mid summer.
- Bend shoots to the horizontal (Gala, Braeburn and Jonagold) or below (Cox, Discovery, Bramley.)
- Increase use of plant growth regulators (such as Cultar and/or Regalis). Aim to stop growth before it becomes too strong, using winter and spring treatments. Timings and rates should be specific to individual orchards. Both materials can have unwanted side effects. Seek advice for specific recommendations.
- Only summer prune to remove strong upright shoots and those shading fruits within the canopy. When summer pruning, remove whole shoots back to their base. Do not head back shoots.
- Poor flowering due to lack of light into the tree canopy

A lack of light within the tree will reduce flower bud numbers and their quality. As shoots tend to grow strongly towards the light, further shading can be induced. Light levels within the tree canopy can be improved by:

- Changing pruning techniques to reduce shading. This is particularly important in the top of the tree to reduce the height and width of the upper tree canopy.
- Creating a well-defined 'A' shaped tree in spindle trees.
- Removing lower branches if they remain shaded.
- Removing strong upright shoots or bending them into a space.
- Reducing the height of windbreaks surrounding the orchard.
- Use of light-reflecting material on the orchard floor

- Poor flowering due to excessive cropping in the previous season

The number of seeds in the fruit produced in the previous season will have a major effect on the numbers of flowers formed. To reduce this effect growers should:

- Thin as early as possible, to reduce the fruit numbers and hence the seed numbers causing the flowering inhibition.
- Not delay harvesting more than two weeks after the optimum date as this can reduce flower numbers, especially if other risk factors (e.g. vigour and shading) are also a problem.

Overcoming biennial bearing

With varieties that have developed a biennial pattern of cropping growers should:

- Prune away excessive spurs in the winter prior to an 'on' year.
- Thin blossom on biennial varieties in the 'on' year.
- Thin, preferably at flowering time, using ATS.

No chemical treatments, other than thinning treatments are approved for use against biennial bearing

Flower quality on mature trees and its improvement

Growers should strive to produce flowers of high quality with an Effective Pollination Period (EPP) of 3 days or more. For optimum flower bud quality:

- Trees should be thinned early in the previous season to optimum crop loads.
- Fruit harvesting should not be delayed too long, as late picking may reduce flower quality on varieties such as Bramley and Braeburn.
- Maintain good tree health status by judicious use of pest and disease control measures.
- Use nitrogenous fertilisers sparingly in the spring and summer prior to harvesting so as to reduce shoot growth which competes with developing flower buds.
- Consider foliar or ground (taking into account Nitrate Vulnerable Zone restrictions) applications of nitrogen in the autumn following harvesting, but before leaf fall, to improve the quality of flowers in the subsequent spring.
- Adopt winter pruning techniques that improve light distribution through the tree but do not encourage excessive growth. This is best achieved by making a few larger cuts.
- "Summer prune" to allow adequate light into the centres of the trees.
- Bend shoots towards the horizontal or below, but this should not be carried out to excess or the optimal balance of new renewal shoot growth and flower bud production will be lost.
- Growers should take note of the average maximum temperatures in February, March and April in their Cox orchards, as these have a significant bearing on flower quality. Where temperatures are higher than desired average maxima (i.e. 10°C or higher), they are advised to intensify their efforts to secure good pollination and flower fertilisation. This can be achieved by supplementing bee populations, providing increased shelter and controlling early growth straight after petal fall using an approved growth regulator. Where temperatures are of the desired average maximum or lower, growers will need to consider implementing appropriate thinning procedures.
Pollination and fruit set are often reduced severely by spring frost damage to the flowers. One possible strategy that has been investigated in attempts to reduce this risk is delaying flowering in the spring using plant growth regulators or other spray treatments.

- Although sprays of various chemicals can influence the time of spring flowering in the previous autumn or winter, none of these treatments are approved for use in UK apple orchards.
- Further research may be warranted, examining misting techniques to delay flowering times of apple varieties.

**Flower quality on mature trees and its improvement**

Flower quality, in terms of ability to set fruits is often estimated by measuring the Effective Pollination Period or EPP.

The flowers formed in the spurs and on short terminal shoots of apple trees are initiated very soon after fruit set in the previous year.

- Approximately 3-4 weeks after petal fall the first floral primordia are visible under high power microscopy in the spurs.
- Providing these buds develop unhindered and differentiate into flowers, they should provide flowers of the highest quality (with long EPPs) in the subsequent spring.

In contrast, flowers forming on the current season's extension shoots, known as axillary buds, are initiated later in the season, usually once the growth of the current season's extension shoots begins to slow down in mid-late summer.

- These axillary buds are, on most varieties, poorer quality; they flower several days later than the flowers on spurs or short terminal shoots and they have shorter EPPs.

Flower bud quality is difficult to quantify but may be best described as the relative ability of the flower to set a fruit.

- However, it is now thought that flower quality may also influence the retention of the fruit after setting and its subsequent rate of growth.
- Flower buds of differing quality are very fully described in Abbott, 1984.
- Other studies have suggested that a good correlation exists between the size of the flower cupula and eventual fruit size (Stosser et al., 1996).

Many environmental and tree management factors influence apple flower quality. The following factors are thought to be the most important influencing flower quality:

- **Crop loading** and flower and fruit thinning (including natural fruit drop).
- Tree health and nutrition.
- Tree pruning/training and flower bud position on the tree.
- Exposure of the sites of flower initiation to adequate light.
- Winter chilling and satisfying the dormancy requirements.
- Spring temperatures prior to bud burst.

**The Effective Pollination Period or EPP**

The most common measurement of flower quality is the Effective Pollination Period or EPP (Williams, 1970). Trials conducted in the 1970s at Long Ashton Research Station (Stott et al., 1973) showed that short EPPs were a common cause of poor fruit set on the early fruiting variety Discovery. Although 9% of flowers set fruits if pollinated on the day of opening (anthesis) only 1% set fruits if pollinated two days after opening.

The EPP is measured by protecting flowers from external uncontrolled pollination by enclosing them in large paper or other bags at the balloon stage of development. After removing the bags (temporarily) some of the flowers are pollinated on the day they open (anthesis). Further flowers are pollinated one, two, three, four or more days later. After each controlled pollination, the bags are replaced until after fruit set.

- Flowers that set fruits only when pollinated on the day of opening, or not at all, have low EPPs and are classed as poor quality.
- In contrast, flowers which can be pollinated 4 or more days after opening and still set and retain fruits have long EPPs and are classed as higher quality.
- In UK conditions, good quality apple flowers should, under orchard conditions, have EPPs of three to five days.

The reasons for these differences in EPPs and flower quality are not fully understood. Most theories relating to apple flower quality focus on differences in the ovules of the flowers.

- Poor quality flowers are thought to have ovules which either have a short life or which develop out of synchrony with the rest of the flower.
- An example of this might be flowers where the ovule becomes receptive to the pollen tube in advance of flower opening but which has begun to degenerate by the time that pollen eventually reaches it.

Flowers that are initiated late in the previous summer, such as those formed as axillaries on one-year-old wood, develop only partially by the autumn and are usually, but not always, of poor quality, with short EPPs in the subsequent spring.
In this instance incomplete or shortened flower development may explain the quality differences. This means that the window of time for effective pollination and fruit set with axillary flowers is much shorter and the risks of poor fruit set much higher than with spur or terminal flowers.

Climatic conditions have a strong influence on apple flower quality, and this is discussed more fully by Williams (1970) and Abbott (1984). The aim of the apple grower must be to encourage the rapid production of high quality flowers on the spurs and short terminal shoots of young trees.

With many of the newer varieties, such as Gala, Braeburn, Kanzi, Jazz and Rubens, axillary flowers can be relied upon to contribute significantly to cropping on young trees. These axillary flowers are more likely to set and produce good size fruit if they are produced on strong wood of approximately 10 mm diameter.

Growers should strive to produce flowers of high quality with Effective Pollination Periods of three days or more. Flower quality is improved by:

- Minimising the spring and summer use of nitrogenous fertilisers, which encourage strong vigorous shoot growth and extended growth into the late summer and autumn.
- Limiting strong shoot growth by branch bending and brutting techniques especially in Cox and Bramley.
- Improving light penetration into the tree canopy.
- Optimising crop loading by appropriate flower or fruitlet thinning techniques.
- Not delaying fruit harvesting too late in the season.

The importance of planting well-feathered trees

Research conducted largely at HRI-East Malling in the 1980s showed the importance of planting high quality trees in increasing flowering in the first few years following planting.

- Tree quality is generally measured in terms of tree height and the numbers of feathers (lateral branches) present on the tree at the time of planting. Trees with six to eight strong feathers with wide branch angles are ideal.
- Another tree quality factor, sometimes ignored, is the health status of the tree. Flowers formed on well-managed healthy trees are invariably of higher quality than those on diseased or poorly nourished trees.
- Some virus infections will have a negative influence on flower quality and fruit set. Wherever possible, trees of high health status (especially virus freedom) should be chosen.

Trees planted as 'whips', with a single leader and few or no feathers, take a minimum of one year longer to begin flowering significantly following planting and are not recommended.

In contrast, maiden trees with 6 to 8 good feathers (lateral branches) at the time of planting begin to flower in the second year (leaf) following planting and by the third year can be producing worthwhile crops.

The first flowers produced on poor quality trees are formed only in the axillaries of the leaves on one-year-old extension shoots and, as such, are usually of poor quality.

On well-feathered trees, the production of high quality flowers on spurs or short terminal shoots on two-year-old or older wood is achieved sooner following planting.

The onset of flowering is advanced and the abundance and quality of flowers improved if well-feathered trees are planted in good fertile soils.

It is also important that these relatively large trees receive good management to minimise the transplanting check to growth. Excessive transplanting check to growth will cause tree stunting and may lead to the production of branches with bare wood.

The use of 'knip' trees (see below) will encourage early fruiting and significant yields can be achieved in the second leaf after planting.

Nursery and other techniques aimed at improving young tree quality

Some apple varieties, such as Spartan and Bramley’s Seedling, are inherently poor in branching and often produce no feathers in the nursery when grown as 'maiden trees' but with the use of special techniques to promote branching can produce a well-feathered 2 yr old nursery tree. Feathering on trees of Bramley, Spartan and other varieties may be improved by:

- Growing trees on for a second year in the nursery.
- Producing the trees using the 'knip boem' or 'snip tree' technique.
- Producing trees using interstems.
- Sequential removal of the lamina (blades) of the leaves at the shoot tip of the scion central leader.
- Spraying trees with 'branching agents'.

Growing trees on for a second year in the nursery

As might be expected, growing 'maiden' trees on in the nursery for a second season greatly improves the number and quality of feathers produced. The height of these feathers above ground level can also be controlled such that fewer of the low and unwanted feathers are produced.
Two-year-old trees are, inevitably, more expensive and growers can expect to pay perhaps 50 pence more for a two-year-old tree.

Usually, nurseries undercut the root systems of the trees at the end of the maiden year, even when the trees are left for a further year in the nursery.

This aids lifting at the end of the subsequent season and encourages more fibrous root systems.

Two-year-old trees are larger at the time of transplanting to the orchard and often receive a slight check to growth following transplanting.

This can be advantageous in reducing shoot growth and increasing the number and quality of the flowers produced.

However, excessive checks to growth and severe tree stress must be avoided.

Producing the trees using the 'knip boem' or 'snip tree' technique

Trees with much improved feathering are produced using the 'knip boem' or 'snip tree' technique which has been common practice amongst the best Dutch nurseries for many years. The benefit of this technique is that a tree of approximate two-year quality is produced within the normal time span needed for producing a maiden tree. Knip boem trees are generally less expensive than two-year old trees produced from maidens grown on for a second nursery season. The methods are as follows:

- Rootstocks are either grafted or budded and grown in the nursery at normal spacings.
- At the end of the first season of growth, a single-stemmed 'whip' is produced. This is headed back to 70 cm height by removing all but the top bud, strong growth is encouraged, with abundant feathers between 70 and 100cm from the ground.

Producing trees using interstems

Trees raised using other scion varieties or rootstocks as interstocks or interstems are generally produced using either the knip boem technique (see above) or as two-year-old trees.

- For the reasons outlined above, such trees are usually better in terms of their feather number and position than maiden trees.
- Often trees purchased from a continental nursery will have an interstem of another scion variety.
- Golden Delicious is a commonly used interstem.
- Such trees should give no problems and will usually come into cropping earlier than similar maiden trees without interstems.

Sequential removal of the lamina of the leaves at the tip of the scion central leader

Research has shown that the removal of the top half of the leaf blades of the unfolding leaves at the tip of the scion central leader can help the induction of feathering.

- These leaves are thought to produce plant hormones, such as auxins, which suppress the growth and development of the lateral buds into feathers.
- By removing them, the buds immediately below the tip are freed from this inhibition and can develop into feathers.
- The process may be carried out three to five times during the growing season, when leader growth is stong.
- It is vital that the apical meristem of the central leader is not removed during this operation.
- The objective is not to pinch the leader, only to remove the unfolding leaf blades immediately below it.

Spraying with chemical branching agents

Research trials in many parts of the world have shown that feathering of apple trees may be improved using sprays of various plant growth regulating chemicals. Three types of chemical branching agents have been shown to have beneficial effects on young apple trees.

- **Auxin transport inhibitors**: Chemicals known as auxin transport inhibitors slow down the movement of auxins from the shoot tip. These auxins inhibit the growth of feather-forming lateral buds on the main stem. Reduction in the auxin flow allows these buds to break and grow into feathers.

- **Gibberellins and cytokinins**: Research conducted principally in the USA has shown that sprays of Promalin can greatly improve feather production on apple trees in their maiden year. Promalin is a mixture of the gibberellins A₄ and A₇(GA₄+7) and the cytokinin, benzyl adenine (BA). Sprays at high volume (at the USA label recommended concentrations) are applied when the scion central leader is growing actively. Unfortunately, Promalin is not approved for use in the UK.

- **Surfactants**: Research conducted in Canada and the USA has shown that, occasionally, certain types of surfactant can, when sprayed onto actively growing apple trees in the nursery, induce feathering. None of the surfactants shown to have this beneficial activity are available for use in the UK.

The influence of rootstock or interstock (interstem)

Precocity of flowering is greatly influenced by choice of rootstock or interstock. Irrespective of the vigour of tree desired, the apple grower should always choose the rootstock, or rootstock/interstock combination, which is likely to induce precocious cropping.

- Trees grafted onto most of the dwarfing rootstocks currently available begin flowering more quickly following planting than trees raised on most of the more invigorating rootstocks.

- However, the semi-vigorous rootstocks MM.106, and M.116 (AR 86-1-25) and the vigorous rootstock M.25 are exceptions to this rule.
All three of these rootstocks induce much better precocity in scions than most other rootstocks in the same vigour categories.

Dwarfing apple rootstocks that induce good floral precocity
<table>
<thead>
<tr>
<th>Rootstocks</th>
<th>Super dwarfing</th>
<th>Dwarfing</th>
<th>Semi-dwarfing</th>
<th>Semi-vigorous</th>
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<tr>
<td>M.27</td>
<td>M.8</td>
<td>M.26</td>
<td>MM.106</td>
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<td>M.20</td>
<td>M.9*</td>
<td>Mark</td>
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<tr>
<td>J-TE-G</td>
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Increasing the height above ground level of budding apple scions onto dwarfing rootstocks increases the dwarfing effect on the scion and may also increase precocity of flowering.
Using a dwarfing rootstock as an interstock, between the scion and a more invigorating rootstock, dwarfs trees more than if trees were raised directly on the invigorating rootstock.
These interstocks also improve precocity of flowering.
Increasing the length of interstock used, up to 25 or 30cm, also increases the effects on scion dwarfing and precocity.

Dutch research has shown that use of other scion varieties as interstems (between the rootstock and the main scion variety) can also improve precocity of flowering.

Interstems, of the varieties Golden Delicious or Zoet Aagt, have both induced such benefits in scions.

The importance of tree age and transplanting 'check'

Trees planted as two-year-olds generally come into flowering quicker than trees planted as one-year-old maidens. Part of this effect is explained by the increased branching (feathering) that is commonly found on two-year-old trees.

However, a recent trial planted at East Malling Research showed that, even when the length and number of feathers on one-year-old and two-year-old trees were approximately the same, the two-year-old trees still came into flowering more quickly following orchard planting.

One possible reason for this effect is the larger/older root system on the two-year-old trees at the time of planting and the possible increased transplanting ‘check’ to growth.

However, it was interesting to note that, in the subsequent years of this trial, the trees planted as one-year-olds grew away better and after several years were outcropping the trees planted as two-year-olds.

A severe transplanting check can be induced by stringfellowing the trees.

This involves cutting off most of the roots to leave very short root stubs at the time of planting.

Trials have shown that stringfellowed trees grow less but form more flower buds in the first one or two seasons following planting.

Another method of causing a temporary check to growth in the first season is to plant the trees late in the spring when higher soil temperatures induce rapid root development and shoot growth has less time to develop.

This results in better quality fruit bud being laid down and improved cropping in the subsequent year.

Successful establishment of trees planted as late as May requires very well prepared soil with a high organic matter content and immediate application of trickle irrigation after planting followed by an intensive fertigation regime.

The storage of trees for up to six months requires specialist cold stores with fogging systems to create a high humidity without wetting the trees and treatments to reduce development of diseases such as Phytophtora and Nectria.

Soil management, irrigation and nutrition

Soils rich in nitrogen and with copious supplies of water induce strong shoot growth and reduced numbers of flowers per metre of shoot length. These flowers are often initiated late in the summer season on account of the prolonged period of extension shoot growth on the vigorous trees. Such late initiated flowers are inevitably poorer in ‘quality’ the following spring than flowers initiated earlier in the summer.

Young trees

- Obtain analyses of the soil mineral and organic matter contents prior to tree planting. Based on these analyses and the current recommendations concerning optimum levels (e.g. Defra recommendations in RB 209) any necessary base dressings should be applied.
Supplementary nutrition of trees in their first or second years following planting should be applied in order to maximise early yields. This is best done by a combination of fertigation and regular applications of a balanced foliar feed. Where this is not possible, apply repeated small doses of a blended fertiliser or a slow release fertiliser in the planting hole. On deep fertile soils that have never been planted with apples these supplementary treatments may not be necessary.

In all cases monitor the tree nutrient levels by leaf analysis during the establishment phase. Supplementary irrigation should be applied, preferably using trickle systems, only when soil moisture deficits reach 50 mm. Recent work has shown the benefit in improving establishment and early yields of using a shallow mulch of composted green waste. This should be used where irrigation is not possible and can give added benefits even where irrigation is applied. On varieties sensitive to bitter pit, care should be taken to only apply a light mulch just after planting as mulch material can contain high levels of potassium. Always ask for, or carry out, a mineral analysis of the compost and ensure that it conforms to the latest British Standards.

**Mature trees**

Avoid excessive use of nitrogenous fertilisers in the early part of the growing season. These fertilisers stimulate excessive growth and have an indirect negative effect on flower quality. However, studies have demonstrated that flower quality can be improved by sprays of urea applied either just before harvest or in the autumn following harvesting.

The reasons for these benefits are thought to be increased meristematic activity in the floral cupula, increased longevity of the ovules and the associated longer EPP. It is also suggested that this encourages the spur leaves to develop almost at the same time as the flowers and that this helps flower quality (Stosser et al., 1996).

Use nitrogenous fertilisers sparingly in the spring and summer prior to harvesting. Consider urea sprays in the autumn, following harvesting but before leaf fall to improve the quality of flowers in the subsequent spring.

**Pruning and training techniques for young trees**

Three types of pruning and/or training techniques are practised on young apple trees:

- Shoot pruning
- Shoot bending, training and brutting
- Root pruning or root restriction

**Shoot pruning**

Ideally newly planted trees should fill their allotted space at planting and, where this is the case, very little pruning is required. If trees are much smaller than the space allowed, early yields will be compromised as growth will need to be stimulated and this will be at the expense of crop. Growth should be encouraged by a combination of pruning, removing all fruit and applying extra nutrients.

One of the potential problems with planting very large, well-feathered trees is the tendency to develop bare wood on branches. This is worse when trees are planted in the spring in cold soil conditions and/or when the tree undergoes a period of stress, especially during the early summer period.

Where a well-feathered tree is planted and fills the space at planting, the leader should be left unpruned. It will then naturally develop short fruiting laterals and sufficient extension growth to achieve the required height without becoming too dominant.

Only where the feathers are too few or too weak and do not fill the space should the leader be pruned. In severe cases, prune back to one bud above the top feather to give maximum growth stimulation to the feathers which also should be tipped lightly. Otherwise tip the leader approximately 20 -25 cm above the top feather.

Six to eight of the optimally positioned feathers, if present, should be retained and the lowest and other unneeded feathers removed.

Remove strong upright feathers which have narrow branch angles and may compete with the central leader. With scion varieties, which have a tendency to produce bare wood later in their life, it may also be wise to tip the retained feathers. Severe pruning of either the leader or the retained feathers will generally delay flowering on the trees and encourage strong vegetative growth.

**Shoot bending, training and brutting**

Horticulturists have known for many centuries that bending shoots of apples towards the horizontal reduces the vigour of extension shoot growth and stimulates increased production of floral buds in the following season. The quality of these flowers is also improved.

With apple scion varieties that produce laterals with upright growth habit, the retained feathers should be bent down towards or below the horizontal and secured in this position.
Where the upright growth habit is not too severe and the stems of the feathers are not too thick, this may be achieved using small weighted pegs.

Alternatively, the young branches are secured using string attached either to the support stake or to W clips pushed into the soil. Partially breaking small laterals on young trees (sometimes called brutting) can also reduce shoot growth and stimulate increased flowering on these shoots:

- Tie down lateral growth towards the horizontal or below this angle on very strongly growing varieties.
- Partially ‘snap’ short laterals formed from the central leader, so as to reduce shoot growth and encourage flowering and fruit set.

Root pruning or root restriction

Research in the USA and at East Malling Research has shown that pruning the roots of young trees, using a deep spade or root pruner reduces subsequent extension growth and increases the production of flower buds (Webster et al., 2000, see Further reading [hyperlink]).

- Unfortunately, if supplementary irrigation and nutrition is not applied, fruit set per tree is not always increased and fruit size at harvest is generally reduced.
- Root pruning is not recommended for use on young newly planted trees.

Planting trees within root restriction membranes buried in the soil has similar effects to root pruning, although effects on final fruit size are usually not so severe.

- The most favourable responses have been achieved using membranes which only partially restrict apple tree root growth.
- Root restriction by planting trees within woven membranes is not thought to be economic, currently, under UK conditions.

Plant growth regulator treatments for young trees

Flowering on newly planted apple trees can be increased indirectly by using plant growth regulator sprays in the nursery year(s), in order to induce improved feathering on the trees.

- Once the young trees begin to establish and fill their allotted space in the orchard, use of a plant growth regulator might be warranted.
- Sprays of Cultar, at low concentration, may aid the production of flower buds and precocious yields on young trees that are growing too vigorously and forming few flower buds.
- Sprays of Regalis at petal fall have been found to encourage fruit set and reduce growth.
- No chemical plant growth regulators are approved for use as branching agents in the UK.
- Low concentration treatments with Cultar may aid flower production on young trees that are growing too vigorously.

Assessing fruit bud numbers and their quality on apple trees

Techniques for collecting a sample of buds and dissecting them to assess flower numbers have been developed. The time in the season when the dissections are made will determine how difficult it is to see the flower primordia and how powerful a microscope will be needed.

In the month or so prior to flowering it is quite easy to determine the presence or absence of flowers and the flower numbers in a floral bud. If, however, the determinations are made during the previous summer and autumn, the assessments are more difficult and require more time.

- Each floral bud will produce on average 5-6 flowers. In a normal year 1 in 6 flowers will set a good fruit, which means that one fruit bud will be needed for each fruit set to provide a good crop.
- A safety margin of 15%-20% over and above this level should ensure adequate fruit numbers at harvest.
- Some varieties e.g. Gala can set more heavily than this, producing on average 2 fruits per bud and, in orchards with a history of heavy setting, bud numbers should be reduced at pruning time especially in shaded parts of the tree and on weak wood.
- Generally, the size (diameter) of the bud is a reasonable guide to its quality. Plump buds are indicative of good quality.

Techniques for winter pruning

Flower numbers are influenced by:

- Light
- Tree vigour
- Food resources available within the tree

One of the main aims of winter pruning is to achieve the correct balance between fruiting and new growth. New growth is required to replace old fruiting wood and provide sufficient leaf area to support the crop.

Poor light levels in the tree will reduce both flower bud numbers and bud quality. Pruning should maximise light interception into all parts of the tree.

Tree shape
The best tree shape is a well defined ‘A’-shape where the height of the tree is 1.5 times its width. (J.E Jackson et al). This shape is easily achieved in semi-intensive orchards but in wide spaced orchards the height will need to be reduced while still maintaining an ‘A’-shape.

Within the tree, create a branch framework of evenly spaced branches which all point down to the edge of the tree space.

**Treatment of the leader**

Do not allow the leader to become too strong or dominant. This can be achieved by:

- Bending the leader into a gently ‘S’-shape.
- Not tying it too tightly to the stake and dead straight.
- Only pruning back into wood that will crop.
- Tearing off unwanted side shoots rather than cutting them off.
- Delaying any necessary pruning until early July.
- Keeping the leader narrow and with plenty of fruit bud.

A technique developed in Holland known as ‘klik’ (stub) pruning can be used in varieties where the leader naturally goes weak.

- In winter the leader is pruned back to a side shoot in the current year’s growth, and the side shoot is ‘klikked’ to 2 or 3 buds.
- In the following year the subsequent regrowth is then stubbed back again in the same way.
- The leader becomes stiffer and can be maintained at a constant height.
- In orchards with strong leaders the technique can also be used but the subsequent growth will be more vigorous.
- Although this technique does keep leaders to a standard height and is a simple method, it means that several cuts have to be made every year.

**Treatment of lower branches**

Improve light by:

- Removing strong upright shoots or bending them into a space.
- Removing heavy timber especially in the top of the tree.
- Where branches are overcrowded remove the dominant, vigorous ones first.
- Avoid ‘stubbing back’ branches as this promotes vigorous shoots further back into the tree, reducing fruit buds and creating more shade. If branches have to be shortened: Cut to 2 to 3 mm above the set of growth rings between one- and two- or two- and three-year-old wood. If a cut is needed further back along the branch always cut to a flat fruiting piece of wood and if this is not available crack the branch down to the correct angle to reduce subsequent growth.

The above techniques refer particularly to Cox. In Gala, Jonagold & Braeburn, cutting to upright shoots may be done without encouraging vigour, especially if the shoots have flower buds already present.

Where trees are too weak, where insufficient replacement wood is being produced or where too many flowers are being produced the following techniques can be adopted:

- Remove weak fruiting spurs and laterals particularly on the undersides or ends of branches.
- Reduce the number of branches, removing weak ones first.
- Stimulate the strength of branches by removing side branches and laterals.
- Check other causes of weak growth such as: poor soil structure, incorrect fertiliser regime, excess use of growth regulators, too heavy cropping.

**Restructuring pruning of old and very large trees**

Old and badly managed orchards are very difficult to get back into full production and it is usually better to grub the trees and replant. However, in a few cases it may be necessary to try and restructure old and very large apple trees.

- Reducing the large size of the trees by severe branch pruning is not to be recommended in isolation, as it will merely stimulate vigorous renewal shoot growth and minimal cropping.
- Hungarian research has shown that where severe branch pruning is essential to reduce the size of very large old trees, supplementary root pruning in the same season can help put the trees back into a better balance (see Brunner, 1990).
- Another alternative is to combine severe branch pruning with applications of plant growth regulators.

**Application of plant growth regulator treatments**

The application of approved plant growth regulators can be a valuable aid to tree management and can lead to a significant increase in flower numbers. Where continued reliance on growth regulators is made year after year, other tree management strategies should also be incorporated.

- It is generally accepted that treatments that retard shoot growth on apple trees usually result in an increase in flower bud initiation.
- The gibberellin-inhibiting chemical paclobutrazol (Cultar) can increase flower induction.
Trials in the UK and abroad have demonstrated increases in floral abundance following use of Cultar (Shearing, et al., 1986). Providing the label recommendations are adhered to, no deleterious effects of the sprays on fruit set or fruit quality should be experienced.

The plant growth regulating chemical, prohexadione-Ca is also available for controlling shoot growth.

- In some, but not all, of the trials the treatments have also improved flower production.
- The product is less persistent than Cultar and the risks of overdosing are minimal.
- Where apple trees are making excessive shoot growth and are flowering poorly, treatments with Cultar will reduce subsequent shoot growth and increase flowering.

Trials over the years have shown the benefit of applying repeated low doses of growth regulators rather than fewer high doses.

- Suppressing growth early in the season before it gets away is also advantageous.
- Exact timings and rates of application are varied subject to individual orchard conditions and the need to reduce any potential side effects and should be discussed with a suitably qualified and experienced advisor.

### Summer pruning

The effects of summer pruning on flower bud formation are extremely variable. This is partly explained by the different techniques of summer pruning employed, the different timings of the pruning and the different responses of scion varieties.

- On spur bearing varieties, any summer pruning which removes entire strong extension shoots back to their base, should have no negative effect on flowering.
- Indeed, in cases where shoot growth on the tree is very dense, such summer pruning should expose the spur buds to light and improve their quality.
- The aim usually is to remove strong upright shoots, which are shading fruits from light.
- In contrast, summer pruning that involves various degrees of heading back (tipping) of extension shoots may have a deleterious effect on flowering.
- Heading back shoots to half or one third their length will stimulate regrowth on the shoots and possibly depress the number and quality of spur flowers produced.
- Tipping or lightly heading extension shoots of some varieties may, however, aid flowering.
- This is mainly beneficial on tip bearing varieties, such as Worcester Pearmain.
- On these varieties, the aim should be to encourage as many as possible short extension shoots (dards or brindles) with strong terminal flower buds.
- Summer pruning of shoots, if carried out at the optimum stage of growth, can encourage this production of short shoots.
- On spur bearing varieties, only summer prune to remove strong upright shoots and those shading fruits within the canopy.
- Remove whole shoots back to their base. Do not head back.
- On tip bearing varieties, light tipping of shoots during the summer may aid the production of short laterals and terminal flowers.
- Where excessive growth is produced regularly and summer pruning is necessary each year to enhance fruit colour development, the need for a change in tree management practices is indicated.

### Trunk girdling (ringing)

It has been known for many decades that partially girdling (or ringing) the trunks of apple trees can increase the numbers of flowers produced in the subsequent season.

- The girdling treatments may comprise a single narrow diameter knife cut, made through the bark into the cambium of the tree for the whole circumference of the trunk.
- Alternatively, it may comprise two slightly wider cuts, usually made one slightly above the other on each side of the tree each for half of the trunk circumference.

Trials at East Malling over the years have shown variable effects of partial girdling (bark ringing) on the subsequent vigour of extension shoot growth.

- Whilst growth is reduced in some trials, in others it is not.
- However, in most trials flowering abundance has been improved following girdling.
- Research in the USA showed that girdling six-year-old trees of the tip bearing variety Cortland 19 days after full bloom increased flowering in the subsequent season but had no effect in the season after that (Greene and Lord, 1983).
- Where trees have become unbalanced, in terms of their excessive shoot growth and poor flowering, girdling (bark ringing) of the trunk may provide a means of improving floral abundance and reducing excessive shoot growth.
- However, this is not a reliable technique and the use of growth regulators and/or root pruning should be used in preference.
• Care must be taken, however, when bark ringing varieties which are sensitive to diseases such as apple canker (*Nectria galligena*).

**Root pruning**

Although root pruning has been shown, in trials at East Malling, to increase the abundance of flowering on young apple trees (*Webster, et al., 2000*), the effects on mature trees are much more variable.

• Trials in the USA on semi-mature and mature apple trees have occasionally increased floral abundance but more often have had no effect on flowering.

• The effects of root pruning on the quality of flowers produced are also variable, irrespective of tree age.

• Severe root pruning of five-year-old Braeburn, Royal Gala, Oregon Red Delicious, Splendour, Granny Smith and Fuji apples on MM.106 rootstock planted in New Zealand trials also increased flowering abundance (as in the trials at East Malling) but reduced yields (*Kahn, et al., 1998*).

• The authors suggest that this yield reduction is brought about by reduced bourse shoot growth following the treatment and the reduced photosynthesis and carbohydrate supply to the roots resulting from this.

• The theory is that it is these root carbohydrates that are so important to fruit set and retention in the subsequent spring.

• Root pruning may be resorted to when other measures have failed to bring over-vigorous apple trees in a balance of shoot growth and fruiting.

• Root pruning on one side of the tree should be tried initially and the effects observed.

• To be effective the treatment should be applied approximately one third to one half of the distance from the trunk to the edge of the tree canopy but no closer than 50cm from the trunk.

• Tree anchorage may be a problem following severe root pruning.

**Crop loading and flower or fruitlet thinning/abscission**

The number of floral buds initiated can be significantly influenced by the crop load set on the trees at the time of initiation and in the few weeks following.

• Flower quality, as well as flower abundance, in the subsequent season is strongly influenced by crop loading and the time of thinning.

• Research conducted at Wye College in Kent (*Buzzard and Schwebe, 1995*) showed that Cox's Orange Pippin trees, that were cropping very heavily in the subsequent spring, developed smaller flowers which had shorter EPPs and lower fruit set than trees with lower crop loads in the previous season. Anatomical differences in the stigmas of flowers from trees of the two different crop loads were demonstrated.

• Flower bud numbers and their quality can also be influenced by the dates of fruit harvesting in the previous season.

• Research conducted at Long Ashton Research Station in the late 1970s (*Williams et al., 1980*) showed that delaying harvesting of Bramley's Seedling fruits reduced flower numbers in the following spring and also the ability of these flowers to set fruits (i.e. their quality).

• Picking in late August gave the best return bloom but reduced total yields significantly; picking in late October reduced flowering number and quality significantly.

• However, in the year of this experiment, the autumn was atypically mild and shoot growth continued very late in the autumn.

• For optimum flower bud quality trees should be thinned early in the previous season to optimum crop loads.

• Fruit harvesting should not be delayed too long as late picking may reduce flower quality on varieties such as Bramley and Braeburn.

**Tree pruning/training and flower bud position on the tree**

Severe branch pruning in the winter and early spring reduces flower quality as well as floral abundance on apple trees.

• The pruning stimulates vigorous shoot growth which often continues late into the autumn.

• This shoot growth competes strongly with the spurs and other sites of floral bud production for photosynthates and minerals.

• The consequence is the production of limited numbers of floral buds, most of which are of relatively poor quality.

• Light pruning generally produces the best flower bud quality on spurs and short terminal shoots.

• Pruning that exposes the sites of floral bud initiation to adequate light is most beneficial.

Bending branches towards the horizontal, or below the horizontal, reduces the rate of extension shoot growth on the branch.

• This in turn results in photosynthates being partitioned more towards the spurs and other sites of flower initiation and away from extension shoot growth.

• These changes have the effect of improving the quality of flowers produced.

Flowers produced on one-year-old extension shoots produced in the previous season (axillary blossoms) tend to have shorter EPPs and hence lower quality than flowers formed on spurs or short terminal shoots.
These differences are partly attributable to the time of flower initiation in the previous season.

- Flowers on axillary shoots are initiated much later than flowers on spurs or short terminals and develop much less by the onset of dormancy in the late autumn.
- Flowers formed on spurs situated on two- or three-year-old wood often produce better quality flowers than spurs formed on older wood.
- Flower bud quality is usually aided by light, rather than severe winter pruning.
- Summer pruning can aid flower bud quality on spurs by removing shading.
- However, where summer pruning entails heading back extension shoots, this may reduce flower bud quality by stimulating late shoot growth.
- Shoot bending improves flower bud quality, but should not be carried out to excess or the optimal balance of new renewal shoot growth and flower bud production will be lost.
- Pruning or training, which encourages the production of more one-year-old shoots and the associated axillary blossoms, is generally detrimental.
- Only on tip-bearing varieties can such techniques be warranted.

**Exposure of the sites of flower initiation to adequate light**

Research at East Malling and in several other countries has demonstrated the importance of good light exposure to the production of high quality flower buds.

- This is particularly relevant in climates such as those experienced in the UK.
- Growers should prune and train their trees so as to ensure good light penetration into all parts of the tree canopy.
- A combination of winter and summer pruning is recommended.

**Winter chilling and satisfying the dormancy requirements**

Apple trees are thought to require an accumulation of an approximate number of hours during the dormant period when temperatures are above freezing but less than 8°C. Figures of 1000 to 1500 hours are often given in the literature.

- Lack of sufficient chilling units is unlikely, on the above evidence, to be a problem in UK apple orchards.
- In most seasons sufficient chilling units have been accumulated by sometime in February.
- Recent studies have been undertaken in Israel, where winters are warm and spring temperatures very hot.
- These have shown that sprays of urea (8%) applied at the stage of green bud swell advanced initial bud break, elevated the total number of flowering buds and significantly increased subsequent yields.
- However, in climatic conditions more suited to apple production, similar benefits of urea sprays have not been recorded.
- Climatic conditions in the UK should provide sufficient chilling units to satisfy the dormancy requirements of traditional apple varieties.
- Problems of insufficient chilling could be experienced if growing within protective structures is contemplated.

**Spring temperatures prior to bud burst**

Although UK apple trees are thought to receive adequate chilling units to satisfy their dormancy requirements, it has been shown that unfavourable temperatures in the spring, prior to bud break, can have a negative effect on subsequent fruit set and yield.

- These negative effects were not caused by very low temperatures and frost damage to blossoms, as might have been expected, but by atypically warm temperatures in February and March and to a lesser extent April.
- The authors of this work, which was mainly carried out by scientists based at East Malling, constructed a model which predicts yields of Cox based on these early spring temperatures.
- Subsequent work in the USA showed that the yields of many of the varieties growing in New York State could be predicted using a similar model.
- Data collected over a number of years indicates that the fruit set of Cox (and its clones) remains high for this variety (30%) in years when the average maximum temperature in February, March and April was no more than 9°C.
- Average temperatures of 10°C or 11°C were associated with much reduced levels of set (<10%).
- The reasons for the negative effect of these early spring temperatures on flower quality are not yet fully understood.
- Subsequent experiments conducted using semi-controlled environments showed that trees experiencing spring temperatures, such that they received 106 day degrees above ambient, set fruits much more poorly than trees receiving 40 day degrees below the ambient (Miller et al., 1986).
- Fruit setting percentages were lower in the 'warmed' trees irrespective of how soon after opening the flowers were pollinated.
- The EPPs were also very much poorer in the flowers of these trees.

Growers should take note of the average maximum temperatures in February, March and April in their Cox orchards.
Where temperatures are higher than desired average maxima (i.e. 10°C or higher), they are advised to intensify their efforts to secure good pollination and flower fertilisation.

This can be achieved by supplementing bee populations, providing increased shelter and boosting supplies of compatible pollinating varieties.

Where temperatures are of the desired average maximum, or lower, growers will need to consider implementing appropriate thinning strategies.

**Overcoming biennial bearing**

It is fortunate that most of the commercial dessert and culinary varieties of apple now grown in the UK have only weak biennial bearing tendencies.

- This is in contrast to several of the popular varieties of cider apples (Tremlett’s Bitter, Vilberie, Reine de Hâtives and Néhou) and to some of the older dessert varieties, such as Blenheim Orange, Miller’s Seedling and Laxton’s Superb, all of which suffered from this problem.
- Amongst popular dessert varieties that are currently grown, only Elstar shows pronounced biennial bearing tendencies.
- Biennial bearing varieties characteristically produce abundant flowers in what is called the ‘on’ season and set heavy crop loads.
- In the subsequent season, the ‘off’ season, they produce few flowers and fruits.

As the initiation of what are likely to be the best quality flowers begins only 3 to 6 weeks after petal fall, the importance of early blossom (flower) thinning is obvious. Whilst the more popular thinning of fruitlets at the 12 mm fruitlet diameter stage will give good benefits in improving flowering in the subsequent season, even better flower quality should be achieved by earlier blossom thinning.

It is interesting to note that the variety Cox and its clones is described as having slight tendencies to biennial bearing in several countries (e.g. New Zealand).

If the UK climate continues to get warmer, resulting in heavier crops that are not thinned correctly, biennial bearing may become more of a problem.

The usual methods employed to overcome biennial bearing are:

- Pruning of flower spurs in the winter prior to the ‘on’ year.
- Thinning of flower using ATS.
- Thinning of fruitlets early in the season.

Other strategies that have been tested in research trials involve:

- Treatments with plant growth regulators.

**Pruning of flower spurs in the winter prior to the ‘on’ year**

The strategy employed here is to remove surplus flower clusters, usually spurs, so that excessive numbers of fruits cannot set in the subsequent spring.

- Knowledge of the variety is essential and the correct degree of spur pruning is only achieved with experience.
- It is also important not to prune the trees so severely so as to induce excessive regrowth in the following year.
- The aim is to achieve the optimum balance of fruit set and growth.
- Prune away excessive spurs in the winter prior to an ‘on’ year.

**Treatments with plant growth-regulating chemicals**

Most of the growth regulating chemicals that have been tested for their efficacy in reducing the problem of biennial bearing have brought about their effect by flower or fruitlet thinning. However, there are a few isolated cases of other chemicals inducing favourable responses.

- Trials conducted at Long Ashton Research Station in 1977 showed that sprays of the chemical bromouracil (50-75 ppm) to biennial-bearing cider apple varieties in the ‘off’ year reduced biennial cropping.

**Sprinkling apple trees in the spring with water**

The evaporative cooling effect of water can be used to delay the flowering of apple trees in the spring. Research conducted at East Malling in the 1970s showed that, by using overhead sprinkler systems, blossoming of Cox’s Orange Pippin could be delayed by up to 14 days (Hamer and Boustred). In further research, the authors attempted to construct a computer model to evaluate the effects of evaporative cooling on apple bud dormancy (see Hamer and Boustred, 1980).

- In these trials, Cox trees were misted with water via overhead sprinklers when ambient air temperatures exceeded 4.5°C.
- The misting commenced in mid February and continued until mid April.
- The buds were cooled by as much as 5°C and this induced a delay in flowering of eight days in comparison with non-misted controls.
- Fruit setting potential (as determined by hand pollination) was significantly improved on the misted trees and these trees produced approximately 30% more yield.
- The misting was shown to have beneficial effects on ovule maturity in the flowers, by reducing the proportion of flowers with over-mature ovules.
Care is needed when using this strategy.

However, an application of excessive misting, whilst maximising bloom delays, increases the water content of the buds, such that they are more, rather than less, sensitive to frost damage (Hamer and Newman, 1981).

Further research may be warranted to examine misting techniques to delay flowering times of apple varieties.

**Physiology of flower initiation and development**

*The processes of flower initiation in apple*

Flowers on apple trees are formed on three types of bud:

- Axillary buds, formed in the basal axils of shoots made in the previous season
- Spur buds formed often in clusters on two-year-old or older wood
- Terminal flower buds, which are formed on the ends of short shoots.

The processes by which these buds are formed are complex. The beginning of floral differentiation is seen as a flattening of the apical dome in a bud which, up to that point, could be considered vegetative.

- Before any visible change in the bud morphology is seen, the meristem of the bud is programmed to form flowers by some, as yet unknown, signal or biochemical stimulus.
- Once the bud transforms from vegetative to floral this process is believed to be irreversible.
- Management or climatic factors occurring after this event may change the quality of the bud but not whether it is floral.

To be sensitive to the inductive stimulus (whatever that may be) and to change to floral type, a bud must be in a certain phase or stage. This is characterised by a critical number of nodes, usually 16-20 (Faust, 1989; Buban and Faust, 1982).

- Additional requirements are a minimum duration (possibly 7 days) of what is known as the plastochron. This is the rate of production of new primordia in the apple bud.
- This plastochron remains very stable throughout long periods of the season, irrespective of climatic conditions.
- However, research at East Malling showed that the length of the plastochron did change, relatively abruptly, during the season and it was usually 5, 7 or 18 days.
- These values are thought to be appropriate for many apple varieties.
- The plastochron is controlled by the younger leaf primordia in the bud, which may themselves be controlled by the foliage.
- It is these changes in plastochron which help to determine whether the buds formed are vegetative or floral.
- A final necessity for buds to become floral is the presence of bracts. For further details see Fulford, (1962); Fulford, (1965b) and Buban and Faust, (1982).

The presence of leaves is a prerequisite for flower bud production and it is believed that increasing numbers of leaves on spurs will increase flower initiation. This effect is probably indirect and operates via its effect on available photosynthates.

*The influence of rootstock and/or interstock on flower initiation and development*

Rootstocks and interstocks have been shown to have a significant influence on flower initiation and development in apple scions. How they bring about these effects is not fully understood.

- It is hypothesised that rootstocks in some way change the partitioning of assimilates (photosynthates) and minerals, such that the sites of floral initiation (e.g. spurs) become strong sinks and the development of increased numbers and better quality floral buds is a consequence of this.
- Part of this change of assimilate partitioning may be explained by rootstock effects on shoot vigour.
- Dwarfing rootstocks bring about slower rates of extension shoot growth during the summer months, but, more importantly, they bring about an earlier cessation of active shoot extension.
- Once the active extension of shoots has stopped and a terminal resting bud is formed, alternative sinks for assimilates in the tree will become more dominant.
- Assimilates will move much more readily to the sites of floral bud initiation in spurs or to roots once active shoot growth ceases.

This explanation is partially flawed, however, as a few invigorating clonal rootstocks (e.g. M.25) stimulate the initiation of many more floral buds on scions than other rootstocks of similar vigour potential.

- This suggests that rootstocks control floral initiation in the scion directly, as well as indirectly via their effects on shoot growth. How they do this is not understood.

Rootstocks do influence the concentrations and movements of plant hormones (auxins, gibberellins, cytokinins and abscisic acid) within the tree (Soumelidou, et al., 1994; Kamboj, et al., 1997).

- It is likely that these differences are in some way involved in their influence on floral bud initiation in the scion.

Another possibility is that as many rootstocks improve the branching angle of scion trees, making branches more horizontal, this could contribute...
indirectly to their effects on floral initiation.

**Effects of pruning and training techniques on flower initiation and development**

Both shoot pruning/training and root pruning/restriction techniques may influence flowering on apple trees.

**Shoot pruning and training**

- It is well known that shoot bending towards or below the horizontal is very effective in inducing increased numbers and quality of floral buds in apple trees.

- What is less well understood is why shoot bending has this effect. It can be suggested that shoot bending slows down new shoot extension, and because new extension leaves form abundant supplies of gibberellins, the result is to reduce the effect of gibberellins on flower bud inhibition.

- However, shoot bending stimulates improved flowering, even when there is no active shoot growth on a branch, indicating a more complex relationship than may at first be apparent (Tromp, 1972).

Research on clones of Red Delicious grown in the USA has shown that summer pruning 30 days after flowering increased spur length and the number, size and area of spur leaves but did not influence flowering spur diameter (Rom and Barritt, 1990).

**Root pruning and restriction**

In trials conducted at HRI-East Malling, root pruning or root restriction of young apple trees has been shown to increase the abundance of flower production (Webster, et al., 2000).

- However, flowering is not always increased by root pruning, as shown by trials on mature Golden Delicious trees growing in the USA (Schupp et al., 1992)

- These USA trials did report an advancement in the time of flowering following root pruning.

- Root pruning causes reductions in shoot growth, a temporary negative water potential, reduced stomatal conductance, transpiration and photosynthesis.

**The effects of defoliation on flower initiation**

Removal of spur leaves on temperate fruit trees is known to inhibit flower production for the subsequent season (Huet, 1973).

- This inhibitory effect may be due to the removal of sites for cytokinin synthesis, which is believed to be important in flower initiation (Hoad, 1980; Ramirez and Hoad, 1981).

The importance of spur leaves has implications concerning the use of certain chemicals for flower thinning.

- Use of urea as a flower thinner may result in reduced flower numbers in the subsequent year.

- Urea often thins by damaging the spur leaves surrounding the flowers.

Work on spur types of Red Delicious growing in the USA has shown that reducing the spur leaf area on non-cropping (vegetative) spurs in August caused a reduction in flower number but not flower size in the subsequent season (Rom and Barritt, 1990).

- Reducing leaf area on the fruiting spurs caused a reduction in the growth of the bourse shoot in the subsequent season.

**The influence of crop load on flower initiation and development**

Attempts to understand how crop load influences flower initiation in apple were made at Long Ashton Research Station in the 1970s (Abbott et al., 1975).

1. The results are shown below:
<table>
<thead>
<tr>
<th>Treatment No.</th>
<th>Total fruit number/tree 1973</th>
<th>No of short shoots/tree (&gt;5 cm) 1973</th>
<th>Length of longest shoot/tree (cm) 1973</th>
<th>Fruit buds /tree 1974</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;60 mm</td>
<td>&gt;60 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>90</td>
<td>79</td>
<td>6.5</td>
<td>46</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>89</td>
<td>7.6</td>
<td>46</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>86</td>
<td>6.9</td>
<td>42</td>
</tr>
<tr>
<td>4</td>
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</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>12.0</td>
<td>85</td>
</tr>
</tbody>
</table>

- It can be seen that high fruit numbers on these small trees reduced shoot growth as well as almost completely inhibiting flowering in the subsequent season.
- However, although return bloom was closely correlated with fruit numbers in the previous year, in this experiment no such correlation was found with the development of flowering buds.
- Anatomical observations of buds harvested from branches sampled throughout the season showed bud development at roughly the same rate.
- The first visible flower initiation was not noted until mid-August and buds from all the treatments achieved this at approximately the same time.
- The experiment indicated that fruit number on trees (crop loading) influences the intensity of flower initiation through some mechanism other than rate of bud development.

However, other work at Long Ashton (Abbott, 1984) indicated that cropping on trees extended the 'plastochron' (the time taken for each node on bud primordia to form) from 8 to 19 days from mid-June onwards; i.e. it slowed down bud development.

- Another effect of heavy crop loads is reduced root development.
- If one accepts the hypothesis that root activity associated with nitrogen assimilation is a necessary stimulus to flower initiation, then this could be an added reason for heavy cropping reducing flowering.
- This might also explain why root pruning, which stimulates root growth at the expense of shoot growth, also stimulates flower production.

Timing of the thinning operation can be critical in influencing return bloom on apple trees. This has been shown to be particularly relevant with varieties such as Boskoop where biennial bearing may be a problem in some seasons.

- Thinning at full bloom or up to two weeks after had a very positive effect on return bloom in the subsequent season.
- However, thinning three weeks after bloom was too late and no more flowers were initiated than on the unthinned controls (Tromp, 2000).
- This is perhaps surprising, as the formation of significant amounts of gibberellins by the fruits (which are believed to be a major cause of flower bud inhibition) had not begun during this three-week period.
- Competition for vital assimilates may play an important role in flower bud initiation in this early post-flowering period.

**Climatic effects on flower initiation and development**

The main climatic effects on flower initiation and development are as follows:

- Climatic effects on flower initiation in the season prior to flowering.
- Climatic effects on winter dormancy.
- Climatic effects on pre-budburst flower quality.

**Climatic effects on flower initiation in the season prior to flowering**

In research conducted many years ago at Long Ashton Research Station, the effects of different day/night temperatures on flower development
were assessed (Abbott and Bull, 1973a).

- Trees of Cox’s Orange Pippin, which were subjected to temperatures of 9°C during the day and 5°C during the night during August to December, reached full bloom at the beginning of April in a glasshouse.

- However, only 23% of the buds were floral and the buds were of what was described as of ‘young’ type.

- The fruitlets on these trees dropped steadily and at harvest only a few ‘king’ fruits remained.

- In contrast, trees retained at 17°C during the days and 13°C during the nights from August to December were slow to break bud in the spring and did not flower until the end of April (three weeks later than the trees subjected to cool autumns).

- With these trees, 70% of the buds were floral and the clusters were typically of the ‘old’ type.

- Fruit drop was less on these trees and concentrated mainly in the June drop period, but the fruits formed were slightly flattened with short stalks.

- The best yielding trees were those subjected to 13°C during the day and 9°C during the night between August and December.

- It is interesting to note that these temperatures were closest to those normally experienced in the orchard.

In research conducted by the same Long Ashton team, the influence of temperatures between the end of April and mid-October on flower initiation of Cox was also studied (Abbott and Bull, 1973b).

- Cox trees subjected to day temperatures of 13.5°C and night temperatures of 7.5°C developed necrotic spots on the primary (spur) leaves which were similar to ‘Cox Spot’ and the new unfolding leaves showed symptoms similar to zinc deficiency.

- Flower numbers in the subsequent spring were average for this treatment but the flowers were variable in their time of opening.

- Other characteristics of this treatment were large spur leaves, a high rate of flower abortion, long bourse or cluster axes, and short flower stalks.

- This all suggests that bud development was slow and flower initiation was late on these trees. The fruits formed were mostly kings.

- Trees subjected to daily fluctuations of 13.5°C and 7.5°C developed bourse shoots, which grew out, and then rosetted and formed short shoots a few cm long.

- This second flush occurred too late for flower buds to develop properly within these spurs and flower numbers were low in the subsequent spring.

- Trees maintained in temperatures of 21.5°C day and 15.5°C night produced ‘old’ type flower clusters with small spur leaves and uniform flowers with long stalks and short bourse shoots.

- Unfortunately, the blossoming abundance on these trees was very variable being inversely related to the fruit numbers/tree carried in the previous summer.

The general conclusion is that higher than average summer temperatures improve flower initiation on apple trees grown in the UK.

- This is thought to be due to the temperatures inducing flower initiation early in the season, allowing more time in the season for successful development of flowers.

- However, care must be taken when trying to use increased temperature to stimulate flowering.

- Trees experiencing high temperatures under glass or polythene structures usually show reduced flower initiation and development.

- This is caused by the stimulation of competitive extension shoot growth and bourse shoot flushing, as well as the lower light levels under protective structures.

Research conducted in Canada has shown that high temperatures (30°C or higher) in June during flower initiation have a deleterious effect on flowering in the subsequent season, as do temperatures over 26°C in August during flower development (Caprio and Quamme, 1999).

- Such high temperatures are unlikely to be a limit on flower initiation in the UK climate.

Climatic effects on winter dormancy

- Apple trees of most scion varieties are believed to require an accumulation of approximately 1000 hours of temperatures of less than 8°C but higher than freezing in order to satisfy their winter chilling (dormancy) requirement.

- Temperatures of above 12°C are thought to result in a loss of some of the accumulated chilling units.

- Many of the ornamental Malus species require several hundred hours less chilling units.

Studies conducted in New York State in the USA in the early 1990s (Hauagge and Cummins, 1991) showed the following chilling unit requirements. The values are means of three years data:
<table>
<thead>
<tr>
<th>Cultivar name</th>
<th>Mean chilling unit requirement (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anna</td>
<td>218</td>
</tr>
<tr>
<td>Delicious</td>
<td>1093</td>
</tr>
<tr>
<td>Elstar</td>
<td>1027</td>
</tr>
<tr>
<td>Empire</td>
<td>1079</td>
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<tr>
<td>Fuji</td>
<td>1077</td>
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<tr>
<td>Gala</td>
<td>1064</td>
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<tr>
<td>Golden Delicious</td>
<td>1050</td>
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<tr>
<td>Granny Smith</td>
<td>1049</td>
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<td>Idared</td>
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<tr>
<td>Prima</td>
<td>1072</td>
</tr>
</tbody>
</table>

In the 1970s, USA researchers developed a chilling unit model (Richardson et al., 1975) for use on peaches and several attempts have been made to use this model with other temperate fruit crops including apple (Shaltout and Unrath, 1983).

- Information more specific to UK conditions was first presented by Landsberg, (1974) and Williams et al., (1979).
- The chilling requirement is primarily needed to the buds themselves (Samish, 1954) but studies in the USA also indicated that for effective bud break in the spring the tree roots also need to be chilled (Young, 1988).

Once the dormancy requirement has been satisfied, the buds are capable of developing into flowers or vegetative shoots if subjected to suitable ‘forcing’ (>15°C) temperatures.

**Climatic effects pre-budburst on flower quality**

It is generally accepted that once the chilling unit requirement has been satisfied and dormancy broken, buds will develop through to flowering if subjected to what are known as forcing temperatures.

- Buds develop at any temperatures over about 10°C, but development is speeded up by higher temperatures.
- The time taken for the flowers to break bud is variable depending upon the scion variety, the bud type and how well the dormancy requirement has been satisfied.
- Temperatures that are unseasonably high during February, March and April (average maxima of 10°C or above) can have a negative influence on flower quality.
- The possible reasons for this effect and its implications are described in the previous section.

**The influence of water supply to the tree on flower initiation**

In experiments conducted in Germany under very controlled environments and water supply, it was shown that when water supply was reduced to 50% or 25% of the trees estimated needs, the numbers of flower clusters and flowers per tree were reduced (Sritharan and Lenz, 1988).

- However, shoot growth was also greatly reduced and when estimates were made of flowering or fruit set per metre shoot length, the drought treatments caused increases in flowering.
- Unless drought is very severe, it is unlikely to influence the efficiency of flower bud production or flower bud quality.

**Effects of tree mineral nutrition on flower initiation and development**

The evidence for mineral supply having a significant influence on flower initiation is only strong when considering nitrogenous fertilisers.

- Applications of high rates of nitrogenous fertilisers, together with sufficient water to facilitate their uptake by the tree, will increase the rate and duration of active shoot growth.
This in turn will delay the initiation and development of floral buds.

One apparent anomaly is that whilst nitrogen is antagonistic to flowering, as stated above, root growth and associated nitrogen assimilation is thought to be vital for flower initiation (Abbott, 1984).

This might be explained by the fact that nitrogen applications whilst extension shoot growth is still active are indeed antagonistic to flower initiation, whereas nitrogen applications after termination of shoot growth often improve flower quality.

For many years there was a theory that flower bud initiation was dependent upon the establishment of a critical ratio between the amounts of carbohydrates and the amounts of nitrogen present; the so-called C/N ratio.

When the ratio is high in favour of carbohydrates then flower bud initiation was thought to occur. However, this theory has now been largely discounted.

The evidence for other elements having a strong effect on flower initiation is poor.

Indeed, in experiments conducted in controlled environment conditions, scientists at Long Ashton Research Station found no significant effect of mineral supply on flower initiation on Cox.

However, these experiments were conducted under glass, where temperatures were higher and light levels lower than those experienced in the orchard.

Subsequent trials at Long Ashton indicated that flower initiation was favourably influenced by an optimal balance of high light, cool temperatures and good nutrition.

**Effects of natural and applied plant hormones on flower initiation and development**

Apple trees produce several chemicals, often called endogenous hormones, which are important in signalling within the tree and in stimulating many vital processes associated with growth and cropping.

Some of these natural hormones, especially the gibberellins, but also auxins and cytokinins, have been implicated in the control of initiation and development of flowers on the apple tree.

Alternatively, chemicals that inhibit plant processes may be used in flower initiation. These are mostly plant growth retardants, which inhibit the tree’s production of gibberellins. The most important of these are:

- Paclobutrazol e.g. Cultar
- Calcium Prohexadione e.g. Regalis

**Gibberellins**

It has been known for many years that gibberellins have an important influence on the formation of reproductive organs in apples and many other seed plants (Pharis and King, 1985).

Applications of gibberellins in spray treatments have been shown to induce parthenocarpy and improve fruit set in apples (Goldwin, 1981) and also to inhibit flowering (Hoad, 1984).

Strong competing shoot growth or excessive numbers of fruits inhibit flowering on apple trees and it can be speculated that gibberellins, formed either in the fruit seeds or in the shoot tips, are the signal hormone responsible for this effect.

Research in Holland showed that both GA\(_3\) and GA\(_7\) strongly inhibit flowering whilst GA\(_4\) has no inhibitory effect on flowering (Tromp, 1982).

Indeed, research conducted in Canada suggests that GA\(_4\) sometimes promotes flowering in apple (Looney et al., 1985).

Work in Germany has supported these findings to some extent. It has shown that, whilst gibberellic acid (GA\(_3\)) is very inhibitory, GA\(_4+7\) has very little inhibitory effect upon flower initiation (Prang et al., 1997).

This work also showed that there was a peak in endogenous (natural) levels of gibberellins (200-450 pg/fruit) in the trees of apple scion varieties at approximately 4-6 weeks after full bloom.

This timing is known to be critical for flower bud initiation.

The problem with this hypothesis, that gibberellins are responsible for inhibiting flowering in apples, is that both biennial varieties, such as Elstar, and non-biennial varieties, such as Golden Delicious, appeared to export approximately the same amounts of gibberellins.

The beneficial effects of GA\(_4\) on flowering, reported by Looney et al., (1985) are not consistent.

In research conducted in the USA (Greene, 1993b), GA\(_4\) has stimulated and increased, as well as reduced, flowering in Golden and Red Delicious trees.

Nevertheless, even when GA\(_4\) induced negative effects on flowering these effects were less severe than those induced by GA\(_7\) at the same concentration.

**Auxins**

Recent studies in Germany (Callejas and Bangerth, 1997) have suggested that the downward (basipetal) transport of the auxin IAA in the apple shoot could play a role in flower initiation.

This hypothesis is based on observations that showed that applications of gibberellins to apple shoots (which are known to suppress flower initiation) increased the amounts of IAA diffusing down from the tips, during the critical stage for flower initiation.

Also, seed number in fruits is known to influence flowering.
The high numbers of fruits, and hence seeds, produced on biennial bearing varieties in their 'on' year is thought to be a major cause of the reduction in flowering in the subsequent 'off' year.

The German work showed that increased seed numbers in fruits were associated with increased auxin transport from the fruits towards the spurs and the sites of potential flower initiation.

**Cytokinins**

Leaves, as well as fruits, have been shown to be the sites of manufacture by the plant of cytokinins.

- The observation that removal of spur leaves from apple trees inhibited flowering in the subsequent season led some researchers to hypothesise that this reduction in flowering was due to the associated reduction in cytokinin supply to the spurs.
- Research by Hoad (1980) lent credence to this hypothesis.
- In this work and in that of Ramirez and Hoad, (1978) it was shown that the inhibitory effect of spur leaf removal on flower initiation could be reversed by local applications of cytokinins to the spurs.

In research conducted by McLaughlin and Greene (1984) the authors suggested that the main influence of cytokinins on flower initiation was in overcoming the negative influence of diffusing gibberellins.

- Applications of the cytokinin benzyl adenine (BA) to fruiting shoots increased the numbers of flowering spurs in the subsequent season whilst similar applications to non-flowering shoots did not.
- The same research showed that BA applications increased the numbers of flowers per spur on both fruiting and non fruiting limbs and the effect seemed to be one of stimulating lateral flower bud formation.
- The effect of BA thinning sprays on return bloom of apples is thought to be entirely due to the effect of the sprays on fruit, or more importantly seed numbers (Greene and Autio, 1994b).

Other cytokinins used for thinning apples, such as CPPU and thidiazuron do not promote return bloom, suggesting that, in comparison with BA, they have some direct negative influence on flower initiation (Greene, 1993).

**Paclobutrazol (PP333 or Cultar)**

Trials at East Malling in the 1980s showed that apple trees treated with paclobutrazol frequently formed more flower buds/tree and many more flower buds/metre shoot length than untreated trees.

- It is thought that this effect is stimulated by paclobutrazol's effect in reducing internode length and shoot length and the partitioning of additional assimilates into the formation of flower buds.

Introduction

World supplies of apples, from both the northern and southern hemispheres have increased significantly over the last 20 years. This has resulted in an oversupply to the European and UK markets in most seasons. This oversupply causes a depression in the prices realised for UK-produced apples and a fall in the profitability of apple growing enterprises.

If apple production in the UK is to continue to be profitable, it will be essential for growers to maximise production of quality fruits per unit cost (land, labour, materials and capital costs). This must be achieved regularly in each season, commencing soon after the establishment of the orchard.

Regular Cropping of Apple is dependent upon having:

- Sufficient flower numbers to set an optimum crop
- Adequate flower 'quality' to enable adequate fruit set
- Good conditions for flower pollination and fertilisation
- The correct numbers of fruits set and retained per tree, so as to optimise final fruit size and quality
- The best conditions and management 'post fruit set' to ensure optimum fruitlet growth

Each one of these factors will be influenced by:

- Temperatures, light levels and other climatic conditions in the orchard
- The growth characteristics of the scion and the influence of the rootstock
- The system of tree management
- Soil water and nutrient supplies
- Hormonal and other internal physiological tree factors


Dennis, F.G. (1979). Factors affecting yield in apple with emphasis on 'Delicious'.


Church, R. and Williams, R.R. (1983). The effects pre-blossom fungicide sprays on the ability of Cox's Orange Pippin apple flowers to produce fruit.


Dennis, F.G. (1979). Factors affecting yield in apple with emphasis on 'Delicious'. Horticultural Reviews, 1: 395-422.


Jones, K.M., Koen, T.B., Oakford, M.J. and Bound, S.A. (1989). Thinning 'Red Fuji' apples with ethephon or NAA.


The physiology of flower and fruitlet drop in apples

The physiology of flower and fruitlet drop in apples

Fruitlets were traditionally thought to drop off in response to the death of their seeds (embryos) and the cessation of the supply of auxins from the live seeds across the abscission zone in the fruit stalk.

- Although embryo death possibly explains a significant proportion of natural fruitlet abscission, it does not explain it all.
- Fallen fruitlets can often be found which have live plump seeds within them.
- Also, research has failed to explain conclusively the causes of the embryo abortion itself.

Hormones occurring naturally within the tree that are associated with flower and fruitlet abscission

- Several natural plant hormones have been implicated in the tree processes leading to flower and/or fruitlet abscission (drop), particularly auxins and ethylene.

Application of plant growth regulators to induce flower and fruitlet abscission

- Various chemicals have been shown to have thinning action when sprayed onto apple trees including, auxins, carbaryl, ethylene releasing chemicals, photosynthesis inhibiting chemicals and cytokinins (benzyl adenine – BA).
- Recent studies have shown that jasmonic acid and n-propyl dihydrojasmonate (PDJ) may have potential as a fruitlet thinner in certain fruit crops (Fujisawa et al., 1997) see Further reading.

Pollination and fruit set and preventing excessive drop of fruitlets

Introduction

If apple production is to be successful it is essential that abundant crops of large high quality fruits are set on trees, in every year. If the break-even point on capital invested in the orchard is to be achieved rapidly and the orchard is to move towards being a profitable investment, it is also essential that the trees begin cropping in the first two or three years following planting.

For these objectives to be achieved it is vital to ensure adequate pollination and fruit set.

The pollination and fruit set of apple trees can be influenced by many factors including:

- The choice of site
- Climatic conditions (and the provision of frost protection)
- The planting of suitable pollinating varieties
- The provision of bees in the orchard
- Various management factors.

Choice of orchard site and its optimisation

Choice of a suitable site for apple production is one of the basic principles of fruit growing that appears in all standard textbooks and articles on apple production. Nothing has changed since this good advice was first put forward centuries ago and, if it is ignored, yields will be variable, especially from varieties that do not have a high setting capability.

Apple trees, provided with an appropriate choice of rootstock, will tolerate a range of site aspects and soil conditions whilst still growing and flowering sufficiently.

- However, in many less favourable situations the trees will fail to be pollinated or the pollen will fail to germinate, grow down the style into the ovary and fertilise the female egg cell in the flower (the ovule).
- Sites which are frosty, or simply cold and windy, at the time of blossoming are particularly unfavourable for pollination and fruit set.

In considering site influences on pollination and fruit set it is essential to pay attention to:

- Site altitude and aspect
- Provision of adequate shelter in the orchard
- Avoidance of frost damage

**Site altitude, aspect and slope**

The following points should be taken into account when choosing a site for an apple orchard:

- Choose a site which is preferably between sea level and 125 meters above sea level.
- Study the cropping history of previous orchards planted on the proposed site, or of neighbouring orchards.
- If available, study meteorological records taken on the site in previous years.
- Avoid sites prone to spring frosts or sites exposed to cold east or north winds.
- Sites with a slight slope to allow the escape of cold air flows are to be preferred.
- Ensure that there are no barriers (buildings or windbreaks), which impede the movement of cold air off the site and create 'frost pockets'.
- Apples can crop on north and east facing slopes but fruit size is likely to be maximised on warmer south facing slopes.
- Sites close to large bodies of water tend to be slightly warmer and less sensitive to frost damage.
- Choose a site which is sheltered from strong winds.

**Provision of adequate shelter in the orchard**

- Plant windbreaks at regular intervals (every 100m) around sites, so as to provide adequate shelter for pollination, but not impede the escape of cold air flows during nights of radiation frosts.
- Choose species such as alders or hornbeam, which are less competitive for water and nutrients than willows or poplars.
- Plant at spacings of 1.0m-1.75m apart in single or, if very good shelter needed, in double rows.
- Trim windbreaks regularly and cut to approximately 7m in height.
- Plant windbreaks several years in advance of planting the orchard trees to ensure adequate shelter when the young apple trees begin to flower.
- Where living windbreaks are not available, use artificial windbreaks.

**Protecting the flowers and young fruitlets from damaging climatic conditions**

**Avoidance of frost damage**

In some seasons, considerable damage to flowers and young fruitlets is caused by frost. Desiccating winds at the time of flowering also serve to kill pollen and inhibit the activity of pollinating insects. Measures that can be taken to reduce potential damage from frosts:

- Avoid sites at high altitudes or the tops of exposed hills where wind frosts are a likely occurrence.
- Ensure flows of cold air down slopes and out of orchards in times of radiation frosts.
- Do not plant windbreaks, which impede this flow.

**Orchard management aids to reducing frost damage**

Management of the soil beneath trees can help alleviate frost damage:

- Most heat loss during radiation frosts (50%-80%) is from the soil surface.
- To help in avoiding damage from radiation frosts, keep soil surface free of weeds and grass, keep soil compact and moist.
- Although the use of canopies or polythene tunnels is widespread on other crops it has not proved economic yet on apples.

**Installation of a frost protection system**

Several methods of providing frost protection to orchard trees have been studied. All of these are used with varying degrees of success in different parts of the world. Only systems based on water sprinkling are currently recommended in the UK. Two types of sprinkler irrigation have been used: under tree systems with micro jets or over tree systems using impact spray nozzles.

**Under tree sprinklers**

- Low level, under tree micro sprinklers can reduce frost damage.
- In calm (no wind) conditions applications of 2 mm water per hour can raise orchard temperatures by 1 or 2 degrees 2 metres above the soil surface.
- Micro sprinklers cause no limb breakage, which is common following extended use of over tree sprinkler systems.

**Over tree sprinklers**

- Over tree sprinkler systems, using impact type nozzles applying 2-3 mm of water per hour during frosts, can provide useful protection to the flowers.
- The advantages of the systems are that they have low running costs and can be used for irrigation purposes as well as frost protection.
- The disadvantages are the high installation costs, the potential for limb breakage due to ice loads on the tree and damage to the soil structure by the large amounts of water applied.
- Water volumes applied can be reduced by use of a 'pulsed' system or by better targeting of the sprays, such that using mini sprinkler nozzles that hit only tree canopies and not the space between.

**Influence of rain on pollination**

Rain during the flowering period of apples reduces the potential for effective pollination and fruit set.

- Firstly, the rain inhibits the foraging activities of all bee species and thus reduces pollen transfer.
- Secondly, rain inhibits the germination and growth of pollen on the stigma and results in pollen death.

**Use of chemical sprays designed to provide some protection from frost and winds**

For many years, scientists have sought to identify products that, when applied to trees, improved the resistance of their flowers to frost damage.
A few varieties show partial self-fertility, especially when temperatures at the time of flowering are high.

Placing the suitable pollinating varieties in sufficient numbers

Most apple varieties are self-sterile and require pollen from another variety to achieve effective fruit set. Pollinating varieties, either other dessert or culinary varieties or ornamental crab apple varieties are planted in the orchard to provide this pollination. Take account of the following when making decisions on choice and abundance of pollinators required:

Summary of pollination requirements of the principal commercial varieties

Varieties differ in their self-fertility and their pollination requirements as noted below:

<table>
<thead>
<tr>
<th>Variety</th>
<th>Pollination Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cox and Queen Cox</td>
<td>Weak self-fertile but only at temperatures of 20-25°C</td>
</tr>
<tr>
<td>Q Cox clone 18</td>
<td>Fully self-fertile</td>
</tr>
<tr>
<td>Braeburn, Fiesta, James Grieve and Gala</td>
<td>Partially self-fertile, will set crops with their own pollen but a pollinator is recommended</td>
</tr>
<tr>
<td>Jonagold</td>
<td>Has the ability to set fruits without pollination (therefore, seedless) given suitable weather.</td>
</tr>
</tbody>
</table>

Other varieties

Partial self-fertility

What constitutes an adequate supply of pollen therefore varies with the variety. It is also influenced by the season and the vigour of the orchard.

The importance of compatibility with the main commercial variety

It is wrong to assume that any two varieties of apple flowering at the same time will always be compatible with each other and capable of setting fruits when pollen is exchanged. Although, given favourable weather conditions during flowering this is mainly true, there are exceptions to this rule:

- Consider choice of pollinators carefully, avoiding unsuitable pollinators, especially on sites where conditions for pollination are less than ideal.
- Do not use triploid varieties, such as Bramley’s Seedling, Jonagold or Boskoop as pollinators for other varieties. They produce only small amounts of pollen most of which is sterile.
- Do not use Red Pippin as a pollinator for Elstar; unless climatic conditions are very favourable the varieties may prove incompatible.
- Do not use Falstaff or Greensleeves as pollinators for Gala; unless climatic conditions are very favourable the varieties may prove incompatible.
- Do not use Gala or Greensleeves as pollinators for Falstaff; unless climatic conditions are very favourable the varieties may prove incompatible.

Partial self-fertility

Partial compatibility, where only 50% of the pollen is capable of growth down the style, may be experienced when using the following varieties as pollinators for Gala:

- Alkmene, Elstar, Galia, James Grieve, Falstaff, Red Pippin.
- Partial compatibility, where only 50% of the pollen is capable of growth down the style may be experienced when using the following varieties as pollinators for Cox:

Consider choice of pollinators carefully, avoiding unsuitable pollinators. This means that they can, given favourable climatic conditions during flowering, set fruits with their own pollen.

Self-fertility

A few varieties of apple show either full or partial self-fertility. This means that they can, given favourable climatic conditions during flowering, set fruits with their own pollen.

Self-fertile clones

Two varieties, Queen Cox Self-fertile Clone 18 and Cox Self-fertile Clone 8, both produced in the last 20 years, are fully self-fertile and can be planted without pollinators.

- Self-fertile Queen Cox clone 18, which is available from UK nurseries, gives more reliable cropping than the traditional self-sterile clones in years unfavourable for pollen transfer between varieties by bees or other insects.
- This self-fertile Queen Cox clone should not be used to pollinate other varieties as it produces insufficient viable pollen.
- Growers considering purchasing self-fertile Queen Cox clone 18 are recommended to obtain this only from a verified source.

Planting partially self-fertile varieties without pollinators

A few varieties show partial self-fertility, especially when temperatures at the time of flowering are high.

- Although several popular apple varieties, such as Red Pippin and Braeburn show a level of self fertility if climatic conditions at flowering time are favourable, this cannot be relied upon to ensure consistent and high yields of fruits on most UK sites.
- Although Braeburn planted without pollinators will set good yields of fruits, these will contain few seeds and will have low levels of calcium.
- The seeds are essential in the uptake of calcium into the fruits and the reduction in bitter pit incidence.
- Varieties such as Gala and Golden Delicious also often set fruits with their own pollen when weather conditions are particularly favourable.
- However, most of the self-fertilised fruits usually drop off at the time of June Drop.
Pollination using ornamental crab apples or other Malus species

Several species of ornamental Malus can prove effective pollinators for commercial varieties of dessert and culinary apples.

- They have the advantage of taking up less space in the orchard than normal pollinating varieties.
- The tried and tested species/varieties are M. hillierii, M. aldenhamensis, M. Professor Springer M. Winter Gold and M. Bereste.
- Always plant several varieties of these ornamental crab pollinators in an apple orchard, not just one.
- Their winter chilling and spring forcing temperature requirements are different from those of the commercial apple varieties and this often leads to lack of synchrony in flowering times.
- Do not neglect the pruning and, where necessary, the thinning of ornamental crabs, or they may go biennial and fail to produce the required flowers in sufficient abundance.

Synchrony of flowering times

For effective pollination it is essential that the main and pollinating varieties flower at approximately the same time period in the spring.

- Choose pollinating varieties which, according to local records, have flowering periods that overlap by a minimum of six days with the main apple variety in the orchard.
- This overlap should be consistent and judged from records collected over a number of years at sites close to the intended site for the new orchard.

Production of adequate quantities of viable pollen by the pollinators

Pollinating varieties for use in orchards of self-sterile varieties of apple must produce adequate quantities of viable pollen.

- The quantities produced are influenced by the scion variety chosen, the rootstock used, the crop loading (on the fruiting crabs), the orchard climatic conditions, the density of pollinating varieties planted and their management.

Scion varieties and their production of viable pollen

Take account of the pollen producing potentials of the varieties chosen as pollinators.

- Varieties such as Golden Delicious produce copious quantities, whilst Cox and its clones produce much less.
- Triploid varieties, such as Bramley and Jonagold produce almost no viable pollen and should not be used as pollinators.
- Do not choose the self-fertile clones of Queen Cox or Cox as pollinators for self-sterile varieties; they produce too little viable pollen.

Rootstock influence on the production of viable pollen by scions

Pollinating varieties grown on dwarfing rootstocks, such as M.9, produce more flowers per unit tree size than the same variety on a more invigorating rootstock.

Trees on dwarfing rootstocks also take up much less valuable space in the orchard.

Crop loading and its influence on pollen production by scion varieties

- Manage the crop loads on the pollinating varieties so as to avoid overset and the establishment of a biennial pattern of cropping.
- Only if thinned well will the fruiting pollinating varieties produce abundant supplies of flowers and pollen on a consistent seasonal basis.

The orchard environment and its influence on pollen quality

- Avoid frost damage to pollinators by good site selection and, where possible, use of frost protection measures.
- In the event of frosts after green cluster, check the pollen viability using simple pollen germination tests.

The ratio between the pollinating variety and the main variety

Generally the pollination ratio should be 1 in 8 to 1 in 10, but in extremes i.e.

- Poor setting, cool sites with excess vigour 1 in 4 to 1 in 6 will be necessary.
- Weak trees of a partially self fertile variety on a good site 1 in 12 to 1 in 15 would be adequate.

Take advice from your local advisor before choosing a ratio of pollinator to main variety for planting in a new orchard. This ratio will be influenced by:

- How favourable the orchard location is, in terms of temperatures and shelter from winds.
- The populations of bees, either wild or introduced in the orchard.
- The pollen producing abilities of the pollinating varieties chosen.
- The propensity of the main commercial scion variety to set abundantly or lightly.
- The compatibility (full or partial) of the chosen pollinating varieties with the main variety.
- Avoid varieties exhibiting a degree of incompatibility as these will give poor results in marginal site/weather conditions.

The management of the pollinating variety [hyperlink 9] in the orchard

The management (pruning and training) of pollinating varieties should aim to stimulate renewal growth and adequate production of quality flowers.

- Apply water and nutrients to pollinating varieties so as to sustain their growth and flowering.

Providing ideal conditions for pollen transfer

Transfer is by insects and to a small extent by wind. Best practice is to achieve an orchard environment which:

- Encourages a wide range of natural insect vectors especially bumble bees by leaving (or creating) grassy sheltered banks and alternative food sources.
- Creates adequate shelter, reduces wind speeds to encourage insect flight.
- Does not reduce wind speed too low, creating stagnant air and no wind transfer of pollen.
Introducing bees where needed

Where these natural levels of insect activity are low, or where pollinator numbers are low and tree vigour is high, pollination can be supplemented by importing hives of honey bees or by encouraging the establishment of bees in the orchard.

- Honey bees will forage more successfully on clear days and when temperatures are above 12°C. Rent healthy, well-stocked (>15000 bees) hives and shelter the hives from cool winds.
- Introduce hive or bumble bees to orchards only when 20% of the flowers are open.
- Introduction earlier may lead to the bees seeking food supplies on other crops growing nearby.
- Once habituated to another crop it is often very difficult to attract the bees back into the apple orchard.

1. Remove (by mowing or use of herbicides) weeds or other species that are flowering in the orchard at the same time as the apples.
- These may prove more attractive to the bees than the apple flowers.
- Avoid broad-spectrum insecticides during blossom.

Improving conditions for pollen germination and pollen tube growth

Germination of pollen

The fertilisation process begins with the pollen falling on the stigma and germinating. Germination requires adequate but not excessive moisture as the pollen grains need to take in water in order to germinate, drying winds will reduce viability.

- Pollen grains lose viability rapidly once wetted so rain will significantly reduce pollination.
- Germination is temperature dependent with optimum temperatures being between 15°C and 25°C.
- Some laboratory tests have indicated that certain pesticide sprays can reduce pollen germination.
- The relation between these tests and the effect in the orchard is not known at today’s spray volumes.
- Dinocap was the most damaging with Captan and sulphur also having some reduction on pollen germination.
- Sprays of penconazole (e.g. Topas) and chlorpyriphos (e.g. Equity and Lorsban) have been shown to reduce fruit set in some seasons if applied during flowering.
- Laboratory tests have shown that boron and calcium can aid pollen germination but field experiments have given very variable results.
- Various plant growth regulating chemicals have been trialled aiming to improve the fruit set and retention of apples, with varying levels of success.

Best practice to increase pollen germination

- Aim to create a sheltered orchard environment in order to lift average temperatures and reduce desiccation from drying winds.
- Avoid any sprays especially on those warm days when germination is the most likely to proceed.
- Avoid spray volumes which thoroughly wet the flowers.
- Provide plenty of pollen as there is evidence that increasing the number of grains on the stigma seems to stimulate germination.
- Ensure that tree nutrition is adequate and they are not deficient in boron or calcium.

Growth of the pollen tube

Following germination on the stigma the pollen tube must grow down through the style to reach the ovule in order to fertilise it.

- Pollen tube growth is almost entirely dependent on temperature.
- Where temperatures are low and the tube does not grow down the style within 2-4 days fertilisation may not occur.
- Some varieties, notably Falstaff and Redsleeves, have pollen that is able to germinate and grow at much lower temperatures.

Best practice for encouraging growth of pollen tube

- Create a sheltered warm environment in the orchard.
- Consider using Falstaff or Redsleeves as pollinators, especially in sites which have marginal spring temperatures.

Successful fertilisation of the ovule

The Effective Pollination Period (EPP) is the number of days after the flower opens during which time it can receive pollen and still set a fruit.

- Some varieties have shorter periods than others.
- Measurements of Cox showed it to be both shorter than other varieties and more variable from year to year.
- The EPP combines the time taken for the pollen to germinate, the pollen tube to grow, and the time during which the ovule remains viable.
- How the EPP is influenced is not understood but aiming for best practice in all the above areas will induce stronger flowers, more viable pollen, better pollination conditions and a higher success rate at fertilisation.

Supplementing pollen supply in the orchard using floral bouquets

In situations where the orchard has insufficient pollinators or these trees have become biennial in cropping it may be necessary to supplement the supplies of flowers/pollen in the orchard.

- Where pollen supply in the orchard is inadequate due to biennial flowering of the pollinators, growers should consider placing floral bouquets in the orchard during the flowering period to supplement pollination.
- Where inadequate pollination is a more consistent problem (i.e. in every year), growers should either interplant the trees with additional pollinators or graft branches of these pollinating varieties into some of the existing trees of the main commercial variety.
The effect of vigour and branch orientation on fruit set and retention

It is clear that training branches of the variety Cox’s Orange Pippin to the horizontal results in better fruit set.

- Trials indicate that the **horizontal orientation** is important not just to flower development but to the success of pollination/fertilisation itself.
- Management practices, which reduce the **vigour** of shoot growth, generally result in improved fruitlet retention.

Site altitude, aspect and slope

- In the UK the most favourable sites are likely to be those at altitudes between sea level and 125 metres above sea level.
- Depending on site topography, wind speed tends to increase whilst temperature and sunshine decrease with increasing altitude.
- Although it would seem that crops such as sweet cherry grow better on south or south westerly aspects, there is no supporting evidence to suggest that apples are similar in this respect.
- A site with a slight slope is recommended, as this allows the steady flow of cold air down the slope away from the trees and gives some protection to their vulnerable flower buds during frosty weather at flowering time.
- No barriers to this flow of air should be permitted, such as ill-sited windbreaks.
- Sites in valley bottoms (often called ‘frost pockets’) should be avoided, as these tend to be prone to frost damage in the spring.
- Sites close to lakes or other large bodies of water can reduce the incidence of frost damage.

Meteorological records taken in previous years can aid greatly in site selection.

- Particular attention needs to be given to the incidence of frost, likely wind speeds and daytime temperatures during the April and May flowering period.
- Temperatures at flowering time of less than -2°C, (at approximately 0.5m above ground level) cause significant damage to the flowers if sustained for one hour or more.
- Although some varieties will set fruits when daytime temperatures are as low as 5°C (e.g. Falstaff), the majority of scion varieties require daytime temperatures of 12-15°C for successful pollen germination and growth.

Previous successful fruit production on a site is not always a good guide for the future.

- Destruction of woodland or the removal of surrounding plantings of large trees or hedgerows in an area can change its climatic suitability significantly.
- Also, global warming is now recognised as a real phenomenon and this may, in future, change the suitability of traditional sites for apple production.
- Unfortunately, the anticipated consequences to weather patterns in the UK are less well known, currently.
- If future predictions suggest the incidence of stronger winds and/or more spring frosts, even more care will need to be taken when selecting sites.

Summary

Choose a site which is between sea level and 125 metres above sea level.

Choose a site which has a slight slope to allow the escape of cold air flows.

Ensure that there are no barriers (buildings or windbreaks) which impede the movement of cold air off the site and create ‘frost pockets’.

Sites close to large bodies of water tend to be slightly warmer and less sensitive to frost damage.

Choose a site which is sheltered from strong winds.

If available, study meteorological records taken on the site in previous years. Avoid low temperature sites.

Provision of adequate shelter in the orchard

Most sites benefit from planting strategically positioned living windbreaks or the erection of artificial windbreaks. These reduce the speed of wind flows across the site in the spring, so reducing the desiccating and chilling influence on the delicate and vulnerable floral organs. Improved shelter and the associated reduced wind speed and higher temperature also encourage the activity of the essential pollinating insects.

Living windbreaks should ideally be established several years ahead of planting the orchard if the early yields on young trees, that are vital to orchard profitability, are to be secured. When planting living windbreaks, it is recommended that deciduous species, which compete strongly for water and nutrients, such as willow (Salix) and some types of poplar (Populus), are avoided.

- Alders are one of the best genera for use as windbreaks in apple orchards and Alnus cordata and Alnus incana are especially suited to the purpose.
- Windbreak trees are generally planted in single rows with plants spaced 1.0 to 1.75m apart.
- In particularly exposed locations, a double row of trees may be warranted, with the rows spaced 2m apart.

Evergreen species are occasionally included as a proportion of the trees in a windbreak.

- These may be of value where the main windbreak species is particularly slow to leaf out in the spring when the protection for flowers is most critical.
- However, windbreaks made up entirely of evergreen species (e.g. Chamaecyparis spp) are, like very dense deciduous windbreaks, not to be recommended.
- This is because they cause excessive air turbulence both up and down wind of the windbreak.

Artificial windbreaks, made from plastic netting on poles and wire, are only rarely used in UK orchards.

- They are relatively expensive and have a limited lifespan.
- However, in the absence of living windbreaks or where the latter are too young to provide adequate shelter to young trees, they can be of transient value.
It has always been recommended that windbreaks are planted/erected at approximately 100m intervals around and across level orchard sites so as to provide adequate shelter for pollination, but not impede the escape of cold air flows.

- They should be kept regularly trimmed and may be allowed to grow to approximately 7m height.
- A well-managed windbreak will provide maximum shelter for a distance of approximately 5 times its height, but some reduced shelter will be achieved up to a distance of 20 times its height.
- On sloping sites, with windbreaks grown across the slope, the base of the windbreak must be kept free of vegetation for a height of 1.5 to 2.0m to allow the unimpeded escape of cold air down the slope in the spring and avoid the creation of mini frost pockets.
- Choose species such as alders or hornbeam which are less competitive for water and nutrients than willows or poplars.
- Plant at spacings of 1.0 to 1.75m apart in single or, if very good shelter is needed, in double rows. Irrigation and fertigation will improve establishment.
- Trim windbreaks regularly and cut to approximately 7m in height.
- Plant windbreaks in advance of planting the orchard trees to ensure adequate shelter when the young apple trees begin to flower.
- Where living windbreaks are not available use artificial windbreaks.

Frost damage

The nature of frost damage to flowers and fruitlets

- At freezing temperatures cells are destroyed in the flower.
- Usually the ovule and style are more susceptible to freezing damage than the pollen (Lormel and Greene, 1931).
- Also, temperatures just above freezing inhibit the fusion of the nuclei in the embryo sac, resulting in only the egg and not the endosperm being fertilised (Konstantinov, 1960).

Research conducted at Long Ashton Research Station in the 1960s (Williams, 1970b) showed that pre-blossoming frosts could have a very damaging influence upon potential fruit set of Cox apples.

- When opening, these flowers appeared undamaged but internal studies showed arrested or abnormal ovule development, leading to an inability to set fruits.
- Further work is needed to enable growers to forecast potential problems caused by frosts that occur prior to flowering.

Poor weather conditions shortly before, during and shortly after flowering of apples can cause significant reductions in fruit set and harvestable yield.

Cold temperatures, especially frost, are the most damaging, although consistent strong winds (>10 mph) will inhibit bee foraging and reduce pollination.

Hail, although unusual at flowering time in the UK, can also, if severe, damage blossoms and young fruitlets.

Two types of frost occur in UK orchards - radiation frosts and wind frosts.

Radiation frosts

- These occur on cloud-free, dry and relatively wind-free nights when the soil, trees and surrounding vegetation lose heat by long wave radiation.
- Cold air builds up from ground level and soon reaches the height of the lowest flowering branches on modern slender spindle trees.
- On sloping sites this cold air flows away down the slope and damage can be avoided by facilitating the free flow of this cold air down the slope.
- Windbreaks must be positioned so as not to impede this air flow.
- In foggy, misty conditions or where there is significant cloud cover this long wave radiation heat loss is reduced and frost damage is less frequent.

Wind frosts

- These occur when air at temperatures below freezing is carried onto the orchard site by winds of varying strengths.
- They are much more common on hilly sites or close to the coast.
- They are best avoided by appropriate choice of site and by the provision of suitable windbreaks.

There are several possible strategies for reducing the worst effects of poor weather conditions. These are:

- Avoid sites at high altitudes or the tops of exposed hills where wind frosts are a likely occurrence.
- Ensure flows of cold air down slopes and out of orchards in times of radiation frosts.
- Do not plant windbreaks which impede this flow.
- Orchard management aids to reducing frost damage.
- Installation of a frost protection system.
- Protecting the trees within canopy structures.
- Use of chemical sprays to trees aimed at providing some protection from frost.

Orchard management aids to reducing frost damage

Soil management

If frost damage is to be reduced, the soil should be kept free of weeds and be uncultivated, i.e. firm and be moist down to approximately 15cm.

- Most heat loss during radiation frosts (50%-80%) is from the soil surface.
- To help in avoiding damage from radiation frosts, keep soil surface free of weeds and grass, keep soil compact and moist.
- Although covering the surface during the day with materials aimed at increasing heat absorption and then removing these in the evening is beneficial, it is also much too labour intensive.

Tree management

- Although contrary to modern systems of management, growing apple trees taller can reduce radiation frost damage.
- A difference of only 30 cm in height in the tree canopy can, on occasions, mean a 1 or 2°C difference in temperature.

Protecting the trees within canopy structures

The low profit margins usually associated with apple production have deterred growers from protecting trees from frost damage using canopies or polythene tunnels. Also, it
is not easy to provide the required amount of heat rise (1-2°C) under covering materials of low cost.

- On cold nights of radiation frosts, radiant heat is lost from the soil in the infra red end of the spectrum.
- To be effective in reducing this heat loss, therefore, the covering material should have low transmittance to infra red long wave radiation.
- Trials conducted at East Malling in the 1970s showed that whilst polyvinyl chloride (PVC) exhibited low infra red transparency, polyethylene and polypropylene showed high transparency (Hamer et al., 1973) and were, therefore, of little value in this respect.

Trials attempting to reduce frost damage using covers of plastic 'Rokolene' netting, erected 3m above ground level, were not very successful (Hamer, 1974).

- Firstly, it was necessary to only put the netting in position when frosts were expected, as otherwise light levels to the trees were reduced excessively.
- Secondly, although the netting reduced the heat loss from the soil to the surrounding air (by 20% to 30%) and flower buds at 90cm from ground level were slightly warmer than those on trees without nets, at 210cm above ground there were no benefits. This was attributable to the net itself lowering the air temperature at this level.

Protecting apple trees from frost or other poor weather conditions at the time of flowering, by enclosing them within plastic or other structures, is not considered to be economic in the UK.

- The costs of applying and removing covers is prohibitively high.
- Leaving trees under covers for extended periods of time causes problems of low light levels, atypical growth, poor fruit quality and reduced flower production.
- Polythene covers provide almost no protection from frost, as they are permeable to long wave radiation. They may prevent damage from wind desiccation, however.

**Suitable pollinating varieties**

Most commercial varieties of apple are self-sterile and require pollen from another variety in order to ensure adequate fruit set. Self-fertile clones of Cox are available and a few other varieties show a level of self-fertility, if given favourable climatic conditions.

The attributes of an ideal pollinating variety are:

- **Compatibility** with the main commercial variety.
- **Synchrony** of flowering time with the main commercial variety.
- **Production** of adequate quantities of viable pollen.

Another important factor is the influence of temperatures and stylar receptivity on pollination efficiency.

A few varieties of apple are self-fertile and able to set a crop of fruits with no need for cross pollination. Also, in a few special circumstances, (usually very high spring temperatures during flowering time), certain varieties of apple which are normally self-sterile exhibit a level of self compatibility and are able to set fruits with their own pollen.

Similarly, some varieties of apple are able to set fruit without the need for fertilisation of the female egg cell (ovule) by pollen. Fruit set of this type is known as Parthenocarpic Fruit Set.

**Compatibility with the main commercial variety**

All commercial varieties of apple are of the species Malus pumila Miller (also sometimes referred to as Malus x domestica Borh.). All the cultivated varieties are very similar and probably the same species as the wild apples found in the forests of several Eurasian countries. These are often referred to as Malus sieversii.

The majority of varieties are self-sterile (cross compatible) i.e. the pollen of one variety is capable of germination, growth and fertilisation of the flower ovules of the other variety.

There are however some significant exceptions to this rule:

- **Triploid varieties** (e.g. Bramley’s Seedling and Jonagold).
- Varieties exhibiting cross incompatibility.
- Varieties that are semi- or partially cross incompatible.

It is also necessary to consider the climatic influences on the compatibility/incompatibility relationships.

**Triploid varieties of apple**

All varieties of apple which have three sets of chromosomes (triploids), rather than the normal two sets (diploids), produce almost no viable pollen and should not be planted as pollen donors for another variety in the orchard.

- In most cases, these triploids can be pollinated efficiently by most diploid varieties.
- However, recent results would suggest that Golden Delicious could prove a very poor pollinator for Jonagold, Crispin and Belle de Boskoop, whilst Summered will also prove a poor pollinator for Jonagold.

Taking account only of compatibility, and not considering synchrony of flowering times, the best pollinators for Jonagold (amongst those so far characterised) appear to be:

- Alkmene, Arlet, James Grieve, Idared and Tydemans Early Worcester.
- Many other varieties, such as Golden Delicious, Cox, Fiesta, Gala, Summered, Falstaff and Worcester Pearmain, exhibit partial compatibility with Jonagold.

Pollen compatibility characterisations on Bramley’s Seedling are still incomplete. However, preliminary evidence suggests that no variety is fully incompatible with it. Partial incompatibility with Bramley is shown by:

- Idared, Golden Delicious, Fiesta, Elstar and Kent.
- Full compatibility with Bramley is shown by Braeburn, Alkmene, Arlet, Cox, Delbard Jubilee, Gala, James Grieve, Worcester Pearmain and Falstaff.

**Some popular triploid varieties of apple**

<table>
<thead>
<tr>
<th>Variety Name</th>
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<tr>
<td>Bramleys Seedling</td>
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Do not use triploid varieties such as Bramley’s Seedling or Jonagold (or its various sports) as pollinators for other varieties.

Do not choose Golden Delicious as a pollinator for Jonagold.

Varieties exhibiting cross incompatibility

Most varieties of apple have two sets of chromosomes (diploids) and are capable of pollinating/fertilising each other, providing they flower at approximately the same time and produce viable pollen.

- However, studies at East Malling characterising what are known as the ‘incompatibility alleles’ in apple varieties, have shown that a few varieties are, in most environmental conditions, incompatible with each other.
- This means that in most circumstances when planted together they will fail to pollinate each other effectively.
- This phenomenon has been recognised in sweet cherry varieties for many years, but it is only recently that it has been noted with apples.
- When pollen from one variety is transferred to the stigma of another with which it is incompatible, the pollen tubes fail to grow down the style into the ovary and no fertilisation of the ovule and fruit set is possible.
- This work also shows that some varieties may prove only partially efficient as pollinators for each other.

Definitive proof of the incompatibility of apple varieties in the orchard situation is, as yet, lacking.

- However, the research suggests that Elstar and Fiesta, in some environmental conditions, will not be able to pollinate each other efficiently.
- The same is true for Falstaff, Gala and Greensleeves. Golden Delicious and Jester will also not fertilise each other efficiently.

Even in apparently incompatible combinations fruit set is often able to occur.

- For instance, trials have shown that when Fiesta received pollen of another variety, with which it should be incompatible, it was able to set a reasonable crop of fruits.
- However, when the reciprocal cross was made, using pollen from Fiesta, no fruit set occurred.

Avoid using ‘incompatible’ varieties to pollinate each other:

- Do not choose to plant Elstar and Fiesta (Red Pippin) with the aim of them pollinating one another effectively.
- Falstaff, Gala and Greensleeves are not fully compatible and in situations unfavourable to pollination and fruit set should not be planted with the aim of mutual pollination.
- Only in situations of warm temperatures at blossom time will the above combinations be successful in pollinating each other.

Varieties which are semi or partially cross incompatible

With any two semi-incompatible or partially compatible varieties, only 50% of the pollen grains produced are able to germinate, grow down the style and set fruit when pollen is transferred between the two varieties.

Cox's Orange Pippin and its sports are only partially compatible with Alkmene, Elstar, Fiesta, Gala, Kent, James Grieve, and Falstaff.

- However, as several of these varieties have been used quite successfully as pollinators in Cox orchards.
- This partial constraint is probably only critical when conditions for favourable pollen production and transfer are severely limited by unfavourable weather conditions.

Similarly, Gala and its sports are only partially compatible with Alkmene, Arlet, Cox, Elstar, Fiesta, Golden Delicious, Summered, James Grieve and Worcester Pearmain.

- In conditions very unfavourable for pollination these varieties may be slightly less efficient pollinators than fully compatible varieties.

Semi-compatibility usually presents little or no problems to the majority of apple growers.

- Studies have shown little difference between the pollen tube growth and fruit set of fully compatible and semi-compatible combinations (Alston, 1996) given reasonable environmental conditions at the time of flowering.
- Indeed, semi-compatible combinations of apple varieties have been recommended for planting in areas experiencing warm temperatures and other favourable climatic conditions at flowering time, as they can help avoid overset and biennial bearing and may reduce the need for fruit thinning (Alston and Tibbutt, 1989).

The potential incompatibility relationships between all the popular varieties of apple have not been characterised. For instance, further research is needed to characterise Braeburn and Bramley’s Seedling.

- Some apple varieties are only partially compatible with each other.
In situations unfavourable to pollen transfer and germination (cool windy sites) these varieties should not be planted together in low ratios of pollinator to main variety for pollination purposes.

**Climatic influences on compatibility/incompatibility relationships**

Temperature at the time of flowering can have a significant influence on pollen germination and at high temperatures (>25°C) incompatible combinations may set fruits quite satisfactorily and many varieties become partially self-fertile. One example is the variety Fiesta, which exhibits increasing levels of self-fertility as temperatures increase up to 15°C (Petropoulu, 1995).

- Frost damages both the male (pollen) and female (stigma, style and ovary) parts of the flowers.
- Improving shelter in orchards and raising ambient temperatures at flowering time can influence the type and number of pollinators required in an apple orchard.
- Pollen germination and growth down the style is greatly aided at temperatures of >15°C.
- At high temperatures (e.g. 25°C) pollination efficiency is improved with variety combinations, which are normally incompatible or show only partial compatibility.
- Winds cause pollen desiccation and often death.
- Frost causes death of pollen and the female parts of the flowers. The damage is not always visible.

**Influence of temperatures and stylar receptivity or pollination efficiency**

Low temperatures (<10°C) can seriously reduce the effectiveness of pollen germination and speed of pollen tube growth down the style (i.e. stylar receptivity).

- Pollen of varieties such as Redsleeves gives high germination percentages and speed of growth, even at temperatures of 8-10°C, whilst the pollen of Spartan and Falstaff are also good in this respect (Petropoulu and Alston, 1998).
- At these same low temperatures, the pollen of Cox and Fiesta germinated poorly.
- At temperatures as low as 5°C, Redsleeves and Spartan were very effective pollinators for Cox, whilst many other varieties performed very poorly.
- Although Fiesta pollen grew poorly at low temperatures, the styles of flowers of this variety were very receptive to pollen of other varieties applied at low temperatures.
- At 15°C, flowers of Fiesta exhibit partial self fertility.

In orchards where temperatures at flowering time are frequently less than ideal for pollination, choose pollinating varieties such as Falstaff or Redsleeves, which produce pollen that can germinate and grow at quite low temperatures.

**Synchrony of flowering times**

If pollinating varieties are to be efficient, it is essential that their flowering periods overlap sufficiently with that of the main variety planted in the orchard.

- In several countries, varieties of apple have been divided into three categories of early, midseason and late flowering types.
- The assumption usually made is that varieties in the same grouping pollinate each other best, there being no other constraints on pollination (e.g. compatibility).

It has also been assumed that varieties in the early and midseason groups, and also in the midseason and late flowering groups, overlapped each other sufficiently to ensure adequate pollination and fruit set.

- These assumptions are not always true.
- In some seasons certain varieties classified in the early and midseason categories do not overlap sufficiently; the same is true for varieties in the midseason and late categories.
- It has been suggested that, unless the flowering date ranges of any two varieties overlap by a minimum of 6 days, they should not be considered as suitable pollinators for each other (Kemp and Wertheim, 1992).
- Therefore choose pollinating varieties which, according to records, have flowering periods that overlap by a minimum of 6 days with the main apple variety in the orchard.
- This overlap should be consistent and judged from records collected over a number of years.

The average dates of full bloom since 1936 at East Malling for the scion varieties Cox’s Orange Pippin and Bramley’s Seedling are displayed in a graph.

**Self fertility**

Most varieties of apple are self-sterile requiring pollination by another variety for successful fruit set. The exceptions are

- Self-fertile clones
- A number of varieties which seem partially self-fertile in specific climatic conditions
- Self-fertility induced by pollen mixtures

**Self-fertile clones**

A programme of breeding using irradiation techniques, begun by Long Ashton Research Station in the late 1960s and transferred to East Malling in the early 1980s, has been successful in producing self-fertile clones of the commercial apple varieties Cox’s Orange Pippin and Queen Cox.

- Two self-fertile clones have been released commercially. Self-fertile Cox Clone 8 is mainly sold into the home garden market.
- Of more interest to commercial fruit growers is self-fertile Queen Cox clone 18, which now accounts for a proportion of the sales of Queen Cox trees in the UK.

In seasons when climatic conditions at flowering time are unfavourable for pollen transfer by bee vectors, these self-fertile clones yield better than the more conventional self-sterile clones.

- Fruit size, colour and storage potential are similar on the self-fertile and self-sterile clones of Queen Cox.
- Self-fertile Queen Cox clone 18, which is available from UK nurseries, gives more reliable cropping than the traditional self-sterile clones, in years unfavourable for pollen transfer between varieties by bees.
- This self-fertile Queen Cox clone should not be used to pollinate other varieties, as it produces insufficient viable pollen.
- Growers considering purchasing Self-Fertile Queen Cox clone 18 are recommended to obtain this only from a verified UK source.

**Partially self-fertile varieties**

Several varieties, such as Braeburn and Fiesta, although not self-fertile in the true sense, seemable to set adequate crops of fruits with their own pollen (Volz et al., 1996; Petropoulu and Alston, 1998).
Such varieties are thought to combine high stylar receptivity and support strong pollen tube growth, even at relatively low temperatures (e.g. 15 degrees C).

When planting such varieties on sites favourable to consistent fruit set, use of fully compatible varieties as pollinators should be avoided if overset is not to be a problem.

However, relying on this partial self-fertility and planting no other pollinators is not to be recommended.

Studies on Braeburn in New Zealand have shown that, when bees were excluded from trees and set was only by selfing, although yields were not reduced, seed numbers and calcium concentrations in the fruits at harvest time were reduced.

This could have severe implications in terms of bitter pit incidence in some situations and planting Braeburn without pollinating varieties cannot be recommended.

Work in Switzerland (Kellerhals and Wrthner-Christinet, 1996) has shown that Gala may set substantial crops of fruits when pollinated with its own pollen or even when left unpollinated.

However, most of the fruits had no seeds and fruit set was much more severe than on trees receiving cross-pollination.

Most of the few fruits that persisted were thought to be parthenocarpic.

However, a few fruit with seeds were produced and partial self-fertility has been reported elsewhere with Gala (Kemp and Wertheim, 1992).

Also, experiments in the Czech Republic (Rapštrein and Blažek, 1996) have shown that although a few varieties, such as James Grieve, Wagener and Ontario are partially self-fertile, they rarely set a full crop of fruit without cross-pollination.

The variety Golden Delicious, which is often considered partially self-compatible in other countries, set fruits very poorly when selfed in trials at Long Ashton Research Station (Bennett et al., 1973).

However, it was noted that some clones of Golden Delicious may prove more self-compatible than other clones and that virus infection may influence this.

Even the variety Cox and its clones seem capable of a level of self-fertility if given suitable climatic conditions.

Trials many years ago at Long Ashton Research Station (Williams and Maier, 1973), showed that at temperatures of 20-25°C Cox flowers were capable of setting fruits with their own pollen.

Using detached flowers held at 20°C, 8% of styles had pollen tubes from selfed pollen that had penetrated their full length and into the ovary after only 2 days and by the third day 70% of the styles had been completely penetrated.

Pollinating the flowers 2-3 days after anthesis and use of high pollen densities on the stigma were also beneficial in inducing this self-fertility.

The term ‘pseudo-compatibility’ was coined for this phenomenon.

In areas of the world with more favourable spring temperatures, such as North Island, New Zealand, it is quite common for Cox orchards to be planted with few, if any, pollinating varieties.

Although several popular apple varieties, such as Red Pippin and Braeburn, show a level of self fertility if climatic conditions at flowering time are favourable, this cannot be relied upon to ensure consistent and high yields of fruits.

Although Braeburn planted without pollinators will set good yields of fruits, these will contain few seeds and will have low levels of calcium.

The seeds are essential in the uptake of calcium into the fruits and the reduction in bitter pit incidence.

Varieties such as Gala and Golden Delicious also often set fruits with their own pollen when weather conditions are particularly favourable.

However, most of the selfed fruits usually drop off at the time of June Drop.

Self-fertility induced by pollen mixtures

Research conducted in the 1970s showed that the variety McIntosh was fully self-sterile and, when pollinated with its own pollen, no fruit set was achieved.

However, if dead pollen of the variety Delicious was mixed with the McIntosh self pollen, successful fruit set was achieved (Dayton, 1974).

This dead pollen, termed ‘recognition pollen’ overcomes in some way the normal rejection of the self-pollen both on the surface of the stigma and in the style.

Seed numbers in the fruits are, however, generally less than if the flowers were pollinated with live pollen of another variety.

The self-fertile clones of Cox and Queen Cox both produce much dead pollen and it is possible that this may account partially for their self-fertility.

Parthenocarpy fruit set

Parthenocarpy is the ability of a variety to set and develop fruits without the need for flower pollination or fertilisation.

Without commercially important varieties of apple show natural parthenocarpy.

A few varieties of apple are able to set fruits and grow these to maturity without need for fertilisation of the female egg cells (ovules) in the flowers and the formation of seeds.

In some instances, pollination is necessary, but not fertilisation; in others no pollination stimulus is required. This fruit set without ovule fertilisation is called ‘parthenocarpy’.

Parthenocarpic varieties could have significant benefits to fruit growers, as the pollination and fertilisation of flowers is not necessary for fruit set.

This could be a significant advantage in springs when climatic conditions are unfavourable for bee activity and pollen transfer.

Also, trials with a naturally parthenocarpic variety, Spencer’s Seedless, show that when it sets fruits parthenocarpically without seeds there is no problem with return bloom (i.e. bienniality).

In contrast, this variety is hand pollinated with pollen from another variety seeded fruits and biennial cropping are induced.

This supports the long held hypothesis that it is the seeds in apples not the fruits per se that cause the reductions in flowerering in the subsequent season when yields are too high.

Breeding for parthenocarpic fruit set has been undertaken as a small part of a programme based at East Malling (Tibbitt, 1994).

Trials conducted in the 1970s showed that parthenocarpic could be induced in Cox and other UK apple varieties using sprays of growth regulators.

The seedless fruits sometimes produced following self-pollination of the apple variety Kent are thought to be due to a phenomenon called ‘stenospermocarpy’ (Spiegel-Roy and Alston, 1982), where fertilisation, followed by early seed abortion, results in seedless fruits of parthenocarpic appearance.

Parthenocarpic fruit set can be induced by spraying mixtures of a gibberellin and an auxin. These mixtures are not, however, approved for use in UK orchards.

Pollination using ornamental crab apples or other Malus species

In the 1960s and 1970s, research at Long Ashton Research Station showed that several varieties of ornamental ‘crab apples’ performed well as pollinators for commercial
varieties of apple such as Cox and its clones (Williams, 1977). Malus aldenhamensis, M. 'Golden Hornet', M. 'Hillieri' and M. 'Winter Gold' were all suggested as suitable pollinating varieties.

Since this initial research, several other varieties such as 'John Downie', 'Evereste' and 'Golden Gent' have been added to the recommended list, following research conducted in France (Le Lézec and Babin, 1980) and the UK.

Flowering crab apples with proven value as pollinators:

- **Malus aldenhamensis** has a weak growing habit with slender twiggy branches easily distinguishable from most fruiting varieties of apple. It flowers regularly and abundantly and the flowers produce large quantities of viable pollen.
- **Malus floribunda** Hillieri is another weak growing crab with thin drooping branches, very distinct from most fruiting varieties. Flowering is abundant and regular and flowers on one-year-old wood help provide a long flowering period. Pollen production is also good. This crab exhibits high resistance to disease.
- **Malus Winter Gold**. In trials at Long Ashton, pollen of Winter Gold, proved poor in pollinating Spartan, Golden Delicious and Cox in 1981 (Williams et al., 1982).
- **Malus Golden Hornet**. A popular pollinating variety in orchards of Cox planted in the 1980s, Golden Hornet does tend to release its pollen prior to opening its flowers and this may occasionally prove problematic (Anon, 1972).
- **Malus Evereste** and **Malus Professor Springer**. These varieties have become popular in Holland and Belgium and are being used successfully in UK orchards though no efficacy studies have been done in the UK.

Use of these crab apple pollinators has advantages:

- They take up minimal space in the orchard and they require no harvesting.
- The traditional planting ratio for Malus pollinators was one tree every three trees of the main variety in every other row of the latter.
- No extra space in the row was provided for the pollinator; the small tree was fitted between two trees of the main variety at their standard spacing.

It is fortunate that most species of Malus are cross compatible with dessert and culinary apple scion varieties and no problems of pollen compatibility are likely when using these species.

- To ensure adequate overlap of flowering dates with the main orchard fruiting variety, use of 2 to 4 different Malus types is recommended in the same orchard.

In studies undertaken in 1979, scientists at Long Ashton calculated the amount of pollen produced by either normal pollinating varieties or Malus selections, and also the time of flowering relative to Cox (Church and Williams, 1980).

- The records show that when weather conditions in the spring are unfavourable poor synchrony of flowering may be a problem with some of the Malus species.
- The best pollen yields per tree on trees planted in 1975/6 came from Malus Winter Gold, Hillieri and Aldenhamensis. However, good pollen yields were also obtained from trees of the more conventional pollinators James Grieve and Golden Delicious.

**Flowering time and pollen production in 1979 on apple varieties and ornamental Malus planted at Long Ashton Research Station (from Church and Williams, 1980)**

<table>
<thead>
<tr>
<th>Variety or Malus species</th>
<th>Flowering time, days before (-) or after (+) Cox</th>
<th>Mean wt. of viable pollen (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50% open</td>
<td>80% open</td>
</tr>
<tr>
<td></td>
<td>Spurs</td>
<td>Auxillary</td>
</tr>
<tr>
<td>Discovery</td>
<td>-5</td>
<td>+3</td>
</tr>
<tr>
<td>Egremont Russet</td>
<td>-5</td>
<td>+4</td>
</tr>
<tr>
<td>Emneth Early</td>
<td>-1</td>
<td>+11</td>
</tr>
<tr>
<td>Golden Delicious</td>
<td>0</td>
<td>+8</td>
</tr>
<tr>
<td>Grenadier</td>
<td>-2</td>
<td>+10</td>
</tr>
<tr>
<td>James Grieve</td>
<td>-5</td>
<td>+9</td>
</tr>
<tr>
<td>Lord Lambourne</td>
<td>-5</td>
<td>+1</td>
</tr>
<tr>
<td>Worcester Pearmain</td>
<td>+1</td>
<td>+9</td>
</tr>
</tbody>
</table>
Use of ornamental crab apples as pollinators in overseas orchards

Research in other countries has also resulted in recommendations for use of ornamental crab apples in USA, German and Dutch apple orchards (Crasweller, et al., 1978; Stainer and Gasser, 1982; Witteveen, 1973).

- In research conducted in Sweden in the early 1980s the flowering times of a range of ornamental crab apples and several fruiting varieties were recorded over a four year period (Goldschmidt-Reischel, 1993).
- The results are shown below.

### Rankings of earliness of flowering of ornamental crab apples used as pollinators in apple orchards in Sweden

<table>
<thead>
<tr>
<th>Variety</th>
<th>Earliness</th>
<th>Variety</th>
<th>Earliness</th>
<th>Variety</th>
<th>Earliness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dolgo</td>
<td>3</td>
<td>Akero</td>
<td>36</td>
<td>Golden Hornet</td>
<td>49</td>
</tr>
<tr>
<td>Robin</td>
<td>4</td>
<td>Silva</td>
<td>36</td>
<td>White Angel</td>
<td>50</td>
</tr>
<tr>
<td>Hopa</td>
<td>25</td>
<td>Kim</td>
<td>39</td>
<td>Aroma</td>
<td>51</td>
</tr>
<tr>
<td>M. sieboldii</td>
<td>29</td>
<td>M. baccata</td>
<td>40</td>
<td>M. floribunda</td>
<td>51</td>
</tr>
<tr>
<td>M. zumi caloc</td>
<td>30</td>
<td>Snowdrift</td>
<td>42</td>
<td>Royalty</td>
<td>52</td>
</tr>
<tr>
<td>John Downie</td>
<td>31</td>
<td>Katy</td>
<td>42</td>
<td>Van Eseltine</td>
<td>54</td>
</tr>
<tr>
<td>Hyslop</td>
<td>31</td>
<td>Mo</td>
<td>44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kerr</td>
<td>33</td>
<td>M. Eleyi</td>
<td>47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rosencrab</td>
<td>35</td>
<td>Ingrid Marie</td>
<td>49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rankings of stage of flowering (all recorded on the same day) range from 1 to 71. 1 is very early (all flowers at petal fall stage) and 71 very late (all flowers still in bud). (From Goldschmidt-Reischel, 1993).

Several species of ornamental Malus can prove effective pollinators for commercial varieties of dessert and culinary apples.

- They have the advantage of taking up less space in the orchard than normal pollinating varieties.
- The tried and tested species/varieties are *M. hillierii*, *M. aldenhamensis*, *M. Golden Hornet*, *M. Winter Gold* and *M. Everest*.
- Always plant several of these ornamental crab pollinators in an apple orchard, not just one.
It is essential to plant sufficient numbers of trees of a pollinating variety within an orchard, to provide adequate quantities of viable pollen. The number of trees of the pollinating variety planted in relation to the numbers of the main variety apple grower. Proportion of it being non-viable (dead). Such damage often occurs at the early stages of budburst when frost damage is not visible and is, therefore, often overlooked by the orchard environment and its influence on pollen quality.

Production of adequate quantities of viable pollen
Pollinating varieties for use in orchards of self-sterile varieties of apple must produce adequate quantities of viable pollen. The quantities produced are influenced by:

- Scion varieties and their production of viable pollen.
- Rootstock influence on the production of viable pollen by scions.
- Crop loading in the previous year and its influence on pollen production by scions.
- The orchard environment and its influence on pollen quality.
- The number of trees of the pollinating variety that are planted in relation to the number of trees of the main variety.
- The management of the pollinating variety in the orchard.

Scion varieties and their production of viable pollen
Varieties such as Golden Delicious have been shown to produce abundant quantities of viable pollen. This is a combined influence of the high numbers of flowers produced and the large quantities of viable pollen produced in each flower.

- Cox and its clones are poorer in this respect, producing fewer flowers per tree and less viable pollen per flower.
- The self-fertile clones of Cox and Queen Cox produce even less viable pollen per flower and should not be used as pollinators in orchards where the main variety needs pollination.
- Triploid varieties, such as Bramley's Seedling, Jonagold and Crispin, produce almost no viable pollen and are, therefore, of no value as pollinators for other varieties.
- Take account of the pollen producing potentials of the varieties chosen as pollinators.
- Varieties such as Golden Delicious produce copious quantities, whilst Cox and its clones produce much less.
- Triploid varieties, such as Bramley and Jonagold, produce almost no viable pollen and should not be used as pollinators.

Rootstock influence on the production of viable pollen by scions
Most apple varieties and crab apples planted only for the purpose of pollinating the commercial apple variety are planted on dwarfing rootstocks, so as to take up the minimum land space within the orchard. This choice of rootstock has the additional advantage of inducing precocious and abundant flowering on the pollinator.

- The increased flowering induced usually also equates with the production of more viable pollen.
- There is no reliable evidence suggesting that rootstocks influence the percentage viability of the pollen produced by flowers of scions worked upon them.
- Pollinating varieties grown on dwarfing rootstocks, such as M9 produce more flowers per unit tree size than the same variety on a more invigorating rootstock.
- Trees on dwarfing rootstocks also take up much less valuable space in the orchard.

Crop loading in the previous year and its influence on pollen production by scion varieties
It is essential that pollinating varieties are not allowed to crop excessively.

- Excessive set and retention of fruits on pollinating varieties can lead to reduction in the number of flowers produced in the subsequent season.
- Occasionally, the flower quality, including pollen viability, may also be influenced deleteriously.
- In extreme cases, the pollinating varieties may go into a cycle of biennial bearing.
- Where this is a potential problem take time to thin the pollinating varieties.

Research conducted on the variety Golden Delicious growing in the Czech Republic (Blažek) showed that, where pollen donors were abundant, seasonal cropping was inconsistent.

- In contrast, where the distances between the Golden Delicious trees and a source of compatible pollen were as much as 500–1000m, cropping was lower but quite consistent, season to season.
- The Czech research suggested that a critical limit, above which symptoms of biennial bearing were noticed, was 5000 to 6000 apple seeds per 100 cm of trunk cross sectional area.
- For many varieties of apple this would mean approximately 1000 fruits per 100 cm of trunk cross sectional area.

Manage the crop loads on the pollinating varieties so as to avoid overset and the establishment of a biennial pattern of cropping.

- Only if thinned well will the fruiting pollinating varieties produce abundant supplies of flowers and pollen on a consistent seasonal basis.

The orchard environment and its influence on pollen quality
Pollen quality is an important factor in successful pollination. Poor weather conditions, especially frost, can damage the pollen during its development and result in a large proportion of it being non-viable (dead). Such damage often occurs at the early stages of budburst when frost damage is not visible and is, therefore, often overlooked by the apple grower.

- Careful monitoring of frost is essential from bud burst onwards.
- Where frost damage to flowers and their pollen is anticipated, growers or advisors can check on the viability of the pollen using a simple test.
- Avoid frost damage to pollinators by good site selection and, where possible, use of frost protection measures.
- In the event of frosts after green cluster, check the pollen viability using simple pollen germination tests.

The number of trees of the pollinating variety planted in relation to the numbers of the main variety
It is essential to plant sufficient numbers of trees of a pollinating variety within an orchard, to provide adequate quantities of viable pollen.

- There is no single ideal ratio of pollinating to main variety trees and no strong scientific evidence on which to make objective assessments.
For the average situation ratios of 1:9 were traditionally recommended in the UK. Lower ratios of pollinator to main variety are recommended (e.g. 1 pollinating variety to 10 or more main variety trees) where:

- Pollinating varieties with high flower abundance and high pollen production (e.g. Golden Delicious) are chosen.
- The pollinating varieties are fully compatible with the main variety (see ‘Pollen compatibility’ section).
- The pollinating varieties flower at the same time as the main variety in most years.
- Orchard environmental conditions are favourable (shelter, aspect) for bee activity, pollen germination and rapid growth down the style.
- The type of tree grown and/or the site lead to the production of well-controlled growth.
- Where several of these criteria are not met the ratios should increase to 1:4 in the worst situations.

Bees tend to work down rows of trees rather than across them:

- Wherever possible the pollinating varieties should be positioned in every tree row rather than in one in two or one in three rows.
- This is less important in bed systems where trees in 2, 3 or more rows are in close proximity.

Another consideration is the maximum distance between the pollinating variety and the main variety. There is evidence to suggest that distances above 15 to 20 m are likely to result in reduced pollination efficiency (Mišić, 1994; Free and Spencer-Booth, 1964).

- More recent trials in the former Yugoslavia indicate that, whilst distance from the pollinating variety was important for Golden Delicious (fruit set and yield better at 5 m than >20 m), for Jonathan there was no similar effect (Mišić et al., 1995).
- Trials undertaken in the Czech Republic showed that efficient pollination of the variety Golden Delicious was achieved with pollinators planted as far as 40 m away (Blažek, 1996).
- It is suggested that this is explained by honey bees making extended foraging trips on some occasions (Free and Durrant, 1966).
- The Czech author also suggests that better pollen mixing occurs when bee hives are located outside the orchard blocks rather than deeply within them.
- Trials in Hungary suggest that for high density systems trained to slender spindles on M.9 rootstock 10-15 m is the maximum distance between trees of the main and pollinating varieties (Soltész, 1997).

Take advice from your local advisor before choosing a ratio of pollinator to main variety for planting in a new orchard. This ratio will be influenced by:

- How favourable the orchard location is, in terms of temperatures and shelter from winds.
- The populations of bees, either wild or introduced in the orchard.
- The pollen producing abilities of the pollinating varieties chosen.
- The propensity of the main commercial scion variety to set abundantly or lightly.
- The compatibility (full or partial) of the chosen pollinating varieties with the main variety.

The **management of the pollinating variety in the orchard**

If pollinating varieties, either standard fruit varieties or ornamental Malus, are to flower consistently, abundantly and produce good pollen, it is essential that they are well-managed within the main orchard. Unfortunately, their management is often neglected or forgotten.

- It is essential that their tree size is maintained within the space allotted to them and excessive fruit set is avoided if biennial bearing is not to be a problem.
- A trial conducted at Long Ashton Research Station in 1979 examined the influence on return bloom of either fruit thinning or summer pruning of pollinating varieties.
- Fruitlet thinning produced most significant benefits with Golden Delicious.
- Although stripping all the fruits off most of the other varieties produced increases in flowering, it is questionable whether these increases warranted the time and effort involved.
- It is possible, of course, that earlier thinning might have given more benefits and that pollen quality (not measured here) may have been improved by the thinning treatments.
- Thinning fruits is probably only warranted with pollinating varieties which regularly set excessive numbers of fruits with high seed numbers, or with varieties known to have biennial bearing tendencies.
- Summer pruning, which is sometimes necessary to control the size of pollinating trees, severely reduced return bloom on Egremont Russet, and Golden Delicious, but effects on the other pollinating varieties were insufficient to cause concern.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Fruitlet thinning treatments</th>
<th>Summer pruned</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>1 to 1 fruit/cluster</td>
</tr>
<tr>
<td>Egremont Russet</td>
<td>207</td>
<td>248</td>
</tr>
<tr>
<td>Discovery</td>
<td>252</td>
<td>217</td>
</tr>
<tr>
<td>G. Delicious</td>
<td>137</td>
<td>257</td>
</tr>
</tbody>
</table>
Creating suitable habitat for wild insects suitable for pollinating

All types of bee and most other pollinating insects visit apple flowers to collect pollen and occasionally nectar.

- It is generally believed that honey bees play an important role in pollinating apple trees (Free, 1970).
- However, others have suggested that, as good crops of apples can often be obtained in conditions very unfavourable to the activity of hive bees, other vectors of pollen must also be involved or the trees must be more self-fertile than expected.
- It has been suggested that wild bees are also important pollinators although others contend that there are rarely sufficient wild bees to do this efficiently.

If bees and other insects are to perform adequately as pollinators, it is essential to create the appropriate climatic conditions within the orchard.

- Wild bees can be encouraged into the orchards by leaving grassy banks on headlands and by planting mixed deciduous species in windbreaks and various wild flower species.
- Flowering plants, such as corn marigold, are attractive to beneficial insects and may also prove attractive to insects involved in pollination.
- Work by the Oxford Bee Company (Gettinby, 2001) has resulted in the development of commercial nesting systems for Osmia rufa, the red mason bee, a UK native.
- Research conducted in several European centres indicates that red mason bees are much more efficient than honey bees in pollinating apples and other tree fruit species.
- They can also fly within a broader temperature range than honey bees and the dense brush of hairs on the underside of the females facilitates improved transfer of loose pollen between flowers.
- American research even reports improved fruit shape and texture, as well as improved yields as a result of pollination by red mason bees.
- The bees make nests in the holes made by beetles in dead wood and hollow plant stems.

Studies by the Oxford Bee Company have shown that one female red mason bee can be as effective in pollination as 120-160 honey bees.

- It is estimated that only 500 red mason bees are needed to pollinate 1 hectare of apples, compared to 60,000 to 80,000 honey bees.
- Fortunately, the red mason bee is not susceptible to the varroa mite which affects other native bees and is estimated to have caused a 45% drop in the number of commercial bee keepers.
- Artificial nests for these bees can now be obtained, which can prevent the bees being attacked by a wasp parasite.
- These should be located in sunny, sheltered south facing positions in the orchard in early spring.
- Further information is available on www.oxbeeco.com.

Attractiveness to honey bees

Unfortunately, apple flowers are not as attractive to honey bees as several other crops. Pear flowers and the flowers of oil seed rape and several weed species prove much more attractive.

Apple varieties may also differ in their attractiveness to bees. Work at Long Ashton Research Station showed that flowers of Golden Delicious were much more attractive to honey bees than those of Cox’s Orange Rippon (Jeffries, et al., 1983). It was suggested that the Golden Delicious flowers had more perfume and that this may have accounted for them being preferred. However, they would almost certainly have also offered more pollen per flower and more flowers per tree than the Cox.

- When introducing honey bees to an orchard, it is important not to do this too early.
- If the introduction is before a significant number of flowers have opened, the bees will forage for better pollen and nectar sources and become habituated (exhibit what is called ‘flower constancy’) to another more attractive crop nearby. It can then prove difficult to encourage the bees back into the orchard.
- Often bees show constancy to flowers of one colour; the reasons for this are not understood.
- It can occasionally have implications for growers using ornamental Malus (Crab apples) as pollinators in orchards.
- Several of these have dark pink flowers and bees may focus either on these or on the white apple flowers, so failing to move pollen between the two efficiently.

- Czech studies have indicated that honey bees tend to prefer trees with abundant blossoms.

- This has serious consequences for varieties which frequently produce only sparse flowering, either as a consistent and inherent trait, or as a result of bienniality.

- In extreme cases, bees could choose to concentrate their foraging on the variety with abundant flowers and rarely visit the one with low flower abundance.

Introduce hive or bumble bees to orchards only when 15 to 20% of the flowers are open.

- Introduction earlier may lead to the bees seeking food supplies on other crops growing nearby.

- Once habituated to another crop it is often very difficult to attract the bees back into the apple orchard.

- Remove (by mowing or use of herbicides) weeds or other species that are flowering in the orchard at the same time as the apples.

- These may prove more attractive to the bees than the apple flowers.

**Introduction of hive bees to aid natural pollination**

When considering the introduction of hive bees (honey-bees) to apple orchards there are several important considerations:

- Are hive bees necessary for pollination of apples?

- Tining of the introduction of bees to the orchard.

- Avoiding competition with other flowering crops.

- ‘Strength’ of the bee colonies.

- Provision of shelter and favourable habitat for bee activity.

- Aids to transfer pollen between bees.

**Are hives of honey bees necessary for pollination of apples?**

There is some dispute amongst experts as to whether bees, especially honey bees, are important for pollination of apple orchards. Whilst UK research (Free, 1970) shows their importance, research elsewhere has often questioned this.

- It can be argued that the number of pollen grains delivered by pollinating insects from the pollinating variety (pollinizer) to the main variety is a measure of the pollination efficiency of these insects.

- Most researchers have endeavoured to compare the quality of different insect species as pollinators, by assessing their performance in isolation i.e. without any interaction with other potential insect species.

- When different insect species visit flowers, however, interactions are possible making it hard to determine their relative efficiency in pollination.

It is argued that effective pollinating insects should:

1. Collect copious amounts of pollen from the pollinizer variety;
2. Deliver sufficient amounts to the stigmas of the main variety;
3. Make multiple visits to flowers depositing viable pollen at each visit and;
4. Be attracted to flowers of both the pollen donor and pollen receptor varieties.

Preliminary studies in New York State, USA (Goodell and Thompson, 1997) compared the efficiency of honey bees (Apis) with bumblebees (Bombus) in pollen removal and deposition within orchards of apple varieties.

- The studies indicated that both species appeared to be equally effective in the collection of pollen from the donor pollinating variety.

- Honey bees seeking nectar may differ from bumblebees in their efficiency of pollen deposition, however.

- This is because with certain varieties of apple with specific floral anatomy (e.g. the ‘Delicious’ variety) the honey bees ‘sidework’ the flowers and fail to deposit pollen on the stigmas.

- Honey bees also carry far less pollen than bumblebees.

- However, if no ‘sideworking’ takes place then honey bees can make more visits and be just as effective if not more effective than bumblebees.

- Further research is needed to extend this USA study.

Recent experiments in Hungary have shown that the intensity of bee visits to an orchard can have a significant influence on fruit numbers set and the seed numbers in the fruits (Benedek and Nyéki, 1997).

- This suggests that on sites where weather conditions are expected to be consistently unfavourable for bee activity, it will be essential to maximise the number of strong bee colonies per acre, if good fruit set and retention is to be achieved.

It has been estimated that approximately 50 pollen grains are transferred to a stigma by insect pollination. This contrasts with hand pollination, which results in the transfer of many hundreds of pollen grains to each stigma (Stosser et al., 1996).

Research conducted in Canada in the late 1920s showed that a strong colony of bees (e.g. >15,000) would, given favourable weather conditions, visit approximately 21 million flowers in a single day.

- At the tree spacings and sizes in vogue at that time, this equated with the flowers open on 20 acres of fruit.

- However, later studies suggested that if only 25% of a similar bee colony carried viable pollen, then they would pollinate all the flowers on 2.7 acres in a day.

- More recent studies suggest that 60,000 to 80,000 bees are needed to pollinate one hectare of apples grown in the UK at commercial spacings (Gettingby, 2001).

- A study in the 1990s went on to suggest that very few bees were needed for effective pollination (Horticultural Education Association, 1962).

- To pollinate 5% of the flowers on an acre of mature apple trees, a population of only 37 insects was needed for 5 hours.

It has been shown that cropping of fruit trees diminishes the further they are located from suitable pollinators, even when bees are present (Free, 1962).

- The explanation for this is that bees have limited foraging areas, they are attracted to other nearby plant species and they tend to work down one row of trees rather than across rows.

It has been suggested that wind borne pollen may also have a role in apple pollination (Burchill, 1965) and experiments have shown that wind borne pollen can collect on apple stigmas (Ruford, 1955).

- However, research conducted by Free (1964) suggested that the importance of wind pollination in apple trees was negligible.

Free's conclusion can be questioned, however, as the insect-proof cages used in this work also inhibited wind movement and the flowers studied were
Some wild bee species, including bumble bees are known to work in less favourable weather conditions than honey bees and may also be useful pollen vectors in orchards.

The importance of bees in the pollination of apple orchards is still disputed by different authorities.

In ideal conditions, one strong hive of bees (>15,000) should be capable of pollinating all the flowers open on a hectare of apples in one day.

For Cox apples, which are an important pollen vector, 15,000 or more bees are essential. Knowing the strength of the bee colonies is essential.

Pre-pollination feeding of hives with sugar may be necessary if colony strength is to be optimised and it may be necessary for growers to help pay for this. Ensure that the hives of bees hired are strong, well-fed colonies with ideally, 15,000 or more bees.

Avoiding competition with other flowering crops

It is essential that all potential pollen vectors, whether natural or introduced to the orchard, are encouraged to focus on transferring pollen within the apple trees.

The presence of flowers of other crops or weed species in close proximity or within the orchard may detract from this necessary focus.

Hive bees tend to be constant to a particular species on an individual trip from the hive when foraging for pollen and nectar. This is called 'flower constancy' and is an important factor in the success of insect pollination of apples, as hive or honey bees have been shown to form the majority of pollinating insects in European fruit plantations.

Studies on the behaviour of hive bees undertaken in Hungary show that flower constancy for pears was very high but was much smaller for apples. Bees prefer the flowers of rape, plum, dandelion and groundsel to those of apple. If we accept that bees do aid pollination, then there must be some exchange of pollen between bees within the hive.

The extent that this occurs is at present not known.

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‘Strength’ of the bee colonies

There is no benefit in paying for the introduction of honey bees to an orchard unless the hives contain strong colonies (e.g. 15,000 or more bees).

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Provision of shelter and favourable habitat for bee activity

Observations have shown that honey bee activity is limited when cloud cover is seven tenths or more, when wind speeds reach 10 mph or more and/or when the temperature is less than 15°C. Anything that can be done in the orchard to lower wind speeds and increase temperatures must aid the pollinating activity of bees.

Endeavour to create sufficient shelter within the orchard to encourage bee foraging.

The ideal is wind speed no higher than 10 mph and temperatures of 15°C or more.

Aids to transfer of pollen between bees: Use of novel aids to pollen dispersal

One of the potential problems with using honey bees as pollen vectors within apple orchards is also often quoted as one of their strengths; namely flower constancy.

Not only do honey bees focus their foraging for nectar and pollen on a single species, they frequently tend to work only in one variety or down one row of trees. If we accept that bees do aid pollination, then there must be some exchange of pollen between bees within the hive.

The extent that this occurs is at present not known.

The majority of pollinating insects in European fruit plantations are honey bees. The presence of flowers of other crops or weed species in close proximity or within the orchard may detract from this necessary focus.

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The majority of pollinating insects in European fruit plantations are honey bees. The presence of flowers of other crops or weed species in close proximity or within the orchard may detract from this necessary focus.

The extent that this occurs is at present not known.
Sprays of fertilisers, either major or trace elements, have often been tried in attempts to improve fruit set. Applying sprays of macro- and micronutrients to aid pollen germination, pollen tube growth and fruit set has been conducted.

Sprays of Captan, penconazole (e.g. Topas) and chlorpyriphos (e.g. Equity and Lorsban) have been shown to reduce fruit set in some seasons if applied during flowering. Surprisingly, and in contrast to the above results, researchers working at Long Ashton Research Station some years ago noted increased cropping of Cox's Orange Pippin following sprays of benomyl at or around blossom time.

Recent studies have tested sprays of benomyl, dodine and penconazole at various concentrations applied to the flowers of Golden and Red Delicious.

The influence of spray chemicals on pollen germination and growth

Studies conducted many years ago (Mcdaniels and Hildebrand, 1940) showed that use of fungicides could inhibit the germination of apple pollen on the stigma.

More recent research has shown that sprays of certain fungicides, when sprayed onto apple trees during flower opening (anthesis) can have a toxic effect on the reproductive organs in the flowers (Bonnor and Tezzi, 1986; Fedke, 1982). It has been suggested that some of the fungicides have an adverse effect on the cytoskeletal apparatus and mitosis within the pollen tube and the maternal tissues (Battistini et al., 1990).

Recent studies have tested sprays of benomyl, dodine and penconazole at various concentrations applied to the flowers of Golden and Red Delicious.

Sprays of the growth regulator paclobutrazol (Cultar) therefore appear to have no negative effects on pollen germination.

Fungicidal sprays are likely to have no measurable effect on fruit set in years when pollen is transferred in abundance by insects and weather conditions are favourable for pollen transfer and growth, as shown previously, benomyl had a negative influence on pollen germination (70% reduction).

Surprisingly, and in contrast to the above results, researchers working at Long Ashton Research Station some years ago noted increased cropping of Cox's Orange Pippin following sprays of benomyl at or around blossom time (Byrde et al., 1976).

This was attributable to the fungicide reducing stigmal infections with various fungi (Williams et al., 1971).

An alternative to the above results was the use of fungicides could inhibit the germination of apple pollen on the stigma.

The above results were often obtained using in vitro tests and are likely to exaggerate slightly the negative influences of fungicides on pollen germination in comparison with field experiences. Nevertheless, it is advisable not to spray these fungicides during flowering wherever possible. Most new fungicides are now tested for their effects on pollen germination and growth and the manufacturers should supply information on the results of these tests.

Surprisingly, and in contrast to the above results, researchers working at Long Ashton Research Station some years ago noted increased cropping of Cox's Orange Pippin following sprays of benomyl at or around blossom time (Byrde et al., 1976).

This was attributable to the fungicide reducing stigmal infections with various fungi (Williams et al., 1971).

Similar increases in yield were reported in South Africa and the UK following sprays of triadimenol (Strydom and Honeyborne, 1981; Church et al., 1984).

Research therefore indicates that sprays of certain pesticides could negatively affect the germination and growth of pollen, if they were applied to open flowers.

The results showed that sprays of Captan, and penconazole (Topas) could all reduce the germination of pollen and influence fruit set on some apple varieties.

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Fungicidal sprays are likely to have no measurable effect on fruit set in years when pollen is transferred in abundance by insects and weather conditions are favourable for its growth.

However, in years unfavourable to pollen transfer and growth, they could have severely deleterious effects on fruit set (Church et al., 1976).

The mechanisms of how these effects are brought about are still not understood.

The influence on pollination and fruit set of the growth regulators paclobutrazol (Cultar) and CPPU (a chemical occasionally used abroad which has cytokinin action) was also evaluated in trials.

The effects of paclobutrazol were variable.

At high rates the sprays had no effect on pollen germination whilst at the recommended rates the pollen germination of Golden Delicious was slightly stimulated and that of Red Delicious slightly depressed.

Sprays of the growth regulator paclobutrazol (Cultar) therefore appear to have no negative effects on pollen germination.

CPPU had no significant effect on pollen germination. Research at Long Ashton showed that sprays of paclobutrazol (1.0 ml l-1) applied to Cox trees between green cluster and petal fall reduced initial and final fruit set (Church et al., 1984).

However, this may have been due to a negative effect of the sprays on the hormone balance within the flower, rather than any direct effect on the pollen.

Insecticides are known to have a very negative effect on bees and other insects (Johansen, 1977) and it is recommended that sprays of most insecticides are suspended during blossoming.

However, their effects upon bee visits (i.e. the attractiveness of the flowers) and pollen germination and growth are less clear.

Trials at Long Ashton Research Station showed that chlorpyriphos (Lorsban, Equity) applied during flowering of Cox trees reduced fruit set (Church et al., 1984). Sprays of Captan, penconazole (e.g. Topas) and chlorpyriphos (e.g. Equity and Lorsban) have been shown to reduce fruit set in some seasons if applied during flowering.

Their effect may be due to their inhibition of pollen germination and growth, as shown by in vitro tests on some of the pesticides.

Alternatively it may be a direct effect on the pollinating insects. It is suggested that, where possible, they are not applied during flowering time.

Applying sprays of macro- and micronutrients to aid pollen germination, pollen tube growth and fruit set

Sprays of fertilisers, either major or trace elements, have often been tried in attempts to improve fruit set.

Spring applications of nitrogenous fertilisers should be avoided where possible, as these can stimulate shoot growth, which in turn reduces fruit set (Hill-Cottingham and Williams, 1967).
Most treatments are focused on improving flower quality, however a few treatments, such as those with either boron or calcium, are aimed at directly stimulating the processes of flower fertilisation.

Studies conducted mainly on bulbous and herbaceous crops have shown that boron, and to a more limited extent calcium can aid the germination of pollen.

- Boron is always added to the sugar solutions or the Agar medium used to test pollen germination in the laboratory.
- Boron has been shown to stimulate pollen germination and also to speed up the growth rate of pollen tubes down the style (Brewbaker and Mujumdar, 1961).

Many attempts have been made to replicate these boron effects on the flowers of apple trees growing in the orchard. Sprays of boron (e.g. boric acid) have been applied either prior to leaf fall in the autumn or in spring just before flowering. The aim in both cases is to increase the boron concentrations within the floral parts. The results of these experiments have proved very variable.

- In trials conducted at East Malling in 1973, three fortnightly sprays, commencing at 80% petal fall, of 'Solubor' (Na2B8O13.4H2O), were applied at 0.15% for the first and 0.25% for the second two sprays.
- The treatments increased the initial set and the set measured after June Drop of Cox's Orange Pippin but by harvest the effect was not statistically significant (Yogaratnam and Greenham, 1982).
- In the subsequent year, initial set was increased but not final set.
- In neither year was crop weight per tree increased and effects on Discovery were also negative.
- A small but non significant increase in Cox fruit set was observed in one year of the same trials, following sprays of 0.5% urea at pink bud and petal fall.
- The conclusion must be that, although occasional benefits in terms of improved fruit set can be achieved using sprays containing boron, the effects are very inconsistent.

Sprays containing boron, applied at various timings between autumn and late spring have given very inconsistent effects on fruit set and retention of apples and cannot be recommended for this use on current evidence.

### Installation of a frost protection system

Damage from radiation frosts may be reduced by applying orchard heating, by sprinkler irrigation, by use of wind machines or by use of fogging systems during the frosts.

- The objective of all of these measures is to alter what is called the thermal regime of the air layer near the ground and to reduce the loss of long wave radiation from the ground and from the trees.
- Scientists at Pennsylvania State University in the USA have attempted to develop a Decision Support System for frost protection.

**Orchard heating**

In the late 1960s and during most of the 1970s frost protection of UK orchards using heating systems was quite popular, but their popularity declined as fuel prices rose. Three types of orchard heater were used: paraffin wax candles (the most popular), propane gas burners and ‘stack heaters’.

- Usually approximately 35 ‘stack heaters’ per acre were recommended, whilst wax candles were positioned between trees in the row at about 8-10m spacings.
- They were able to provide temperature lifts of 1 to 2°C on nights experiencing radiation type frosts. The life of the propane gas and stack heaters was estimated to be 5-10 years.
- The heaters provided radiant and/or convection heat which increases the temperature of the air and the crop surfaces.
- Although these systems operated best under low wind conditions, they were one of the few methods of frost protection that will help under wind frost conditions. This is explained by the radiant energy they produced.
- A current problem concerning their use is the pollution they cause and in many areas their use is proscribed.

Research has shown that combinations of heaters with wind machines provide more benefits than would be expected from their additive effects. Experiments combining orchard heaters with porous covers have also been carried out with the aim of providing some protection under wind frost conditions but the benefits were not as great as expected.

- Orchard heating during frosty nights can provide some reduction in damage from radiation frosts, by raising temperatures 1-2°C.
- However, the fuel costs for such systems are high and the pollution of the aerial environment caused by the candles, or propane/paraffin burners is usually unacceptable.

**Sprinkler irrigation**

Sprinklers used for frost protection in apple orchards may be high level (overhead) or low level (under tree) in type.

**Under tree sprinklers**

Under tree micro-sprinklers or spray jets are the most common forms of frost protection used in California and Florida, in the USA.

- The aim is to transfer the heat contained in the irrigation water to the surrounding air, whilst maintaining the soil temperature at around 0 degrees C by release of fusion heat when water and ice co-exist on the soil surface.
- Under tree sprinklers are most appropriate where only small lifts in temperature are required and the system is flexible in that it can also be used for irrigation and nutrition at other times of the year.
- Sprinklers applying approximately 2mm/hour can raise temperatures at 2m above the surface significantly, if conditions are calm with no wind.
- The treatment is most effective if applied in humid conditions to soils, which are already moist.
- It is most useful with tree crops that are in full leaf at the time of application, but may also be of value with deciduous trees such as apples with less canopy cover.
- As with over tree sprinkling, ‘pulsing’ of the under tree micro-sprinklers has also been investigated, as a means of saving on water use.
- One particular advantage of the technique is that limb breakage, occasionally a problem with over tree sprinklers, is not a problem with these low-level systems.
- When using over tree sprinkling this is often a problem due to excessive ice build up on nights of extended freezing.
- Low level, under tree micro sprinklers can reduce frost damage.
- In calm (no wind) conditions applications of 2mm/24 hours to compact and previously moist soils can raise orchard temperatures by 1 or 2 degrees 2m above the soil surface.
- Micro sprinklers cause no limb breakage, which is common following extended use of over-the-tree sprinkler systems.
Over-the-tree sprinklers

This technique works by the release of the latent heat of fusion as the water lands on the tree and is turned into ice.

- It is essential that this is a continuous process and that the surface of the ice layer is not allowed to freeze completely.
- The tree tissues are, in efficient systems, maintained at approximately 0 degrees C.
- There is an additional advantage in that some of the heat in the water droplets applied also serves to lift the temperature of the air in the tree canopy slightly.
- Over-the-tree sprinkler systems, using impact type nozzles applying 2-3mm of water per hour during frosts, can provide useful protection to the flower.

The advantages of overhead sprinkler systems are:

- Once installed the running costs are low.
- The heat release is directly to the plant surface and not indirect via the canopy air.
- They cause no air pollution.
- The equipment can also be utilized for other management operations in the orchard, such as irrigation application.

The disadvantages of over-the-tree sprinkler systems are:

- The high installation costs
- The potential for limb breakage with excessive ice build up
- The possibility for excessive evaporative cooling and hence enhanced frost damage.
- The fact that it is essential that sufficient water is applied during the frost event; if too little is applied then frost damage may be worse than if none at all is applied.
- In addition, if the frost persists for many hours very large quantities of water are applied.

Sufficient water supplies must be available to meet this demand and the soils beneath the trees must be capable of draining the applied water away.

- The rates of water application needed vary to some extent in relation to wind speeds and to dew points.
- Uniformity of water distribution is of paramount importance for success with these systems.

Most conventional systems utilise medium pressure impact-drive sprinklers.

- Average application rates of 3.8 or 3.0mm/hour are recommended to achieve minimum application rates of 3 or 2mm/hour respectively.
- New Zealand research has shown that the very high water volumes used can be reduced by approximately 30% by using a targeted mini sprinkler system suspended above the trees.
- This saves water by not spraying between the rows and the headlands.
- Also, it is argued that when water application rates are inadequate to account for a severe frost, the damage resulting will be spread more evenly throughout the orchard using this targeted approach in comparison with the damage in an orchard protected with the medium pressure impact sprinklers.

Another method of saving on water used is to ‘pulse’ the sprinkler applications (Hamer, 1980) and 15-70% savings can be made using this technique.

- This uses a temperature sensor in the orchard, which is designed to respond the same way as a flower or bud
- It causes the system to switch on when the temperature of the sensor falls to below -1 degree C. Nevertheless, this pulsed system does have its problems and advice should be sought from experts before adopting it.

Wind machines

In the most commonly experienced radiation frosts, ground based temperature inversions occur. This means that the temperatures above the tree canopy are higher than the temperatures below and within the canopy of the orchard.

- The aim of the wind machine is to mix these two air layers and to pull some of the higher and warmer air down into the orchard.
- The machines comprise large two-bladed fans (5m in diameter) mounted on towers approximately 10m in height.
- The fan should rotate around the top of the tower once every 4 to 5 minutes.
- The fan blades are mounted with a small downward tilt to facilitate the vertical movements of air.
- Although expensive to install, the wind machines have a 10-20 year life and cause almost no gaseous pollution (compared with orchard heaters) although noise pollution can be a serious problem.
- Nevertheless, they can be expensive to run and are only effective in conditions where strong inversions occur.
- Where nocturnal winds are more frequent their effectiveness will be less.
- Given strong inversion conditions a modern machine of approximately 75 kW can provide a 1 degree C lift in temperature over an area of 3.5ha.
- Use of wind machines for frost protection in UK orchards is not popular.
- The reasons are the high costs of installation and the unproven effectiveness of such machines in UK frost conditions.

Fogging systems

Clouds and fog can modify night temperatures because water droplets of a specific size (10 μm) can intercept a proportion of the long wave radiation loss from the soil and trees and bounce it back towards the surface. The fog also precipitates on the crop surface and, as it freezes, releases latent heat of fusion.

- Successful systems, which generate fog, have been used on vines in France and citrus crops in the USA.
- Fog generating lines placed 6-8 metres above the crop canopies produced a 1-3 m layer of fog, which spread over 300 to 500m in the slight wind.
- A line of 100m length gave some protection to 1-3ha.
- It is essential for success that wind speeds are no more than 0.6-1.0m per second.
- The fog generating lines must deliver at least 25 grams/metre/second for any chance of success.

A mobile fog generating system has also been developed: the Gill saturated vapour gun.

- The system relies on a jet burner using diesel fuel at a rate of 150 litres/hour to generate a high-speed jet of very hot gases.
- Water is injected into this jet of gases via nozzles at a rate of 2 cubic metres per hour.

Water is injected into this jet of gases via nozzles at a rate of 2 cubic metres per hour.
The aim of the apple grower must be to encourage the rapid production of high quality flowers on the spurs and short terminal shoots of young trees. Associated with ovule degeneration and death. Pollinations made after the Effective Pollination Period (EPP) has expired still result in pollen germination and growth of the pollen tube into the ovary. Failure to set fruits in these cases must therefore be the result of poor quality flowers.

For most diploid varieties of apples grown in reasonable temperate climatic conditions, EPPs of three to five days are normal. Early work by Abbott (1984), applied to Cox’s Orange Pippin and its various ‘sports’, showed significant differences between varieties and seasons in terms of their EPPs. In the early 1990s, scientists in the USA produced a prototype decision support computer programme for the protection of crops from frost (Heinemann et al., 1992). The aim was to assist managers with the development, implementation and management of frost protection systems.

Use of chemical sprays to provide some protection from frost and winds

Sprays of plant growth regulators, antitranspirants and other compounds

Although sprays of plant growth regulators have been reported to influence the winter hardiness of trees, these treatments have very little direct effect on the frost tolerance of apple flowers. In research conducted in Washington State and Australia, the dodecyl ether of polyethylene glycol (DEPEG) has been shown to have cryoprotectant activity on the flowers of both apples and blackcurrants.

Applying sprays to alleviate frost damage, to induce parthenocarpic fruit set and to aid fruitlet retention

Sprays of gibberellins, auxins and cytokinins

In the 1970s and 1980s, research conducted by scientists at Wye College in Kent on Cox and its clones showed that sprays of a mixture of gibberellic acid, an auxin and a compound exhibiting cytokinin-type activity could induce parthenocarpic fruit set and increase yields of apples (Kotob and Schwabe, 1971; Goldwin, 1978; Goldwin, 1981).

The Effective Pollination Period or EPP

The most common measurement of ‘flower quality’ is the ‘Effective Pollination Period’ or EPP (Williams, 1970). According to Williams, the EPP is the difference between the number of days that the pollen tube requires to reach the ovules and effect fertilisation of the embryo sac and the number of days the ovules remain viable and receptive after anthesis (flower opening). In laymen’s terms, this means the number of days after the flower opens during which time it can receive pollen and still set a fruit.

Trials conducted in the 1970s at Long Ashton Research Station (Stott et al., 1973) showed that short EPPs were a common cause of poor fruit set on the early fruiting variety Discovery. Although 9% of flowers set fruits if pollinated on the day of opening (anthesis) only 1% set fruits if pollinated two days after opening.

The EPP is measured by protecting flowers from external uncontrolled pollination by enclosing them in large paper or other bags at the balloon stage of development. After removing the bags (temporarily) some of the flowers are pollinated on the day they open (anthesis). Further flowers are pollinated one, two, three, four or more days later. After each controlled pollination, the bags are replaced until after fruit set.

Flowers that set fruits only when pollinated on the day of opening, or not at all, have low EPPs and are classed as poor quality.

In contrast, flowers which can be pollinated 4 or more days after opening and still set and retain fruits have long EPPs and are classed as higher quality.

In UK conditions, good quality apple flowers should, under orchard conditions, have EPPs of three to five days. The reasons for these differences in EPPs and flower quality are not fully understood. Most theories relating to apple flower quality focus on differences in the ovules of the flowers.

Poor quality flowers are thought to have ovules which either have a short life or which develop out of synchrony with the rest of the flower.

An example of this might be flowers where the ovule becomes receptive to the pollen tube in advance of flower opening but which has begun to degenerate by the time that pollen eventually reaches it.

Flowers that are initiated late in the previous summer, such as those formed as axillaries on one-year-old wood, develop only partially by the autumn and are usually, but not always, of poor quality, with short EPPs.

In this instance incomplete or shortened flower development may explain the quality differences.

This means that the window of time for effective pollination and fruit set with axillary flowers is much shorter and the risks of poor fruit set much higher than with spur or terminal flowers.

Climatic conditions have a strong influence on apple flower quality, and this is discussed more fully by Williams (1970) and Abbott (1984).

Early work by Williams (1965) showed significant differences between varieties and seasons in terms of their EPPs.

Whilst a variety such as Scarlet Rumpy exhibited long EPPs (nine days) in each of the two seasons measured, Cox’s Orange Pippin flowers showed five days in one season and only two days in another.

For most diploid varieties of apples grown in reasonable temperate climatic conditions, EPPs of three to five days are normal.

The variety Cox’s Orange Pippin (and its various ‘sports’) has been shown to have a short EPP (Williams, 1970), as has the variety Discovery (Stott et al., 1973).

Pollinations made after the EPP has expired still result in pollen germination and growth of the pollen tube into the ovary. Failure to set fruits in these cases must, therefore, be associated with ovule degeneration and death.

The aim of the apple grower must be to encourage the rapid production of high quality flowers on the spurs and short terminal shoots of young trees.
With many of the newer varieties, such as Gala, Braeburn, Kanzi, Jazz and Rubens, auxiliary flowers can be relied upon to contribute significantly to cropping on young trees. These auxiliary flowers are more likely to set and produce good size fruit if they are produced on strong wood of approximately 10 mm diameter.

Growers should strive to produce flowers of high quality with Effective Pollination Periods of three days or more. Flower quality is improved by:

- Minimising the spring and summer use of nitrogenous fertilisers, which encourage strong vigorous shoot growth and extended growth into the late summer and autumn.
- Limiting strong shoot growth by branch bending and brufting techniques especially in Cox and Bramley.
- Improving light penetration into the tree canopy.
- Optimising crop load by appropriate flower or fruitlet thinning techniques.
- Not delaying fruit harvesting too late in the season.

**Computer models for predicting fruit set**

In the early 1980s scientists working at Long Ashton Research Station, developed mathematical models for use in investigations of the many variables involved in fruit set and fruit drop (Brain and Landsberg, 1981).

- The authors argued that as the number of fruits harvested per tree accounted for 70% of the yield variation for apples (Landsberg, 1980), the processes involved in determining fruit set and retention were critical in determining apple yields.
- Although much research was conducted in the late 1960s and 1970s which pointed to the importance of planting suitable pollinating varieties and of introducing bees for pollen transfer between cross-compatible varieties, the efficacy of these measures in improving yields was considered difficult to estimate.
- This was because of the many variables involved in pollination and fruit set and the difficulties of controlling them.
- To help solve this problem Brain and Landsberg developed mathematical models for pollination and fruit drop, which they attempted to use to analyse the consequences of variable ovule fertility, effective pollination period (EPP) and insect activity.
- The authors constructed a model, which takes account of the EPP, the ovule fertility, the insect visiting rate and the probability that insects will be carrying viable pollen.

Using the model, Brain and Landsberg suggested that, although variability in the length of EPPs for flowers may have an effect on pollination success, it is not an important factor determining yields.

- They hypothesised that the most important factor was insect visiting rate.
- They went on to suggest that placing high numbers of hives in orchards was much more important than either planting high densities of pollinating varieties or ensuring that bees were carrying compatible pollen (hive inserts etc.).
- The authors discussed the feasibility of using the model to predict fruit set but believed that two important components of the model, namely the insect visiting rate and the probability that a bee visit will result in successful fertilisation of an ovule, would prove very difficult to quantify.

More recently, researchers in the USA developed a computer model for predicting fruit set on ‘Delicious’ apple trees (Degrandi-Hoffman et al., 1995). This is available in a PC compatible version, which makes predictions for Golden Delicious and Granny Smith, as well as for Delicious (Degrandi-Hoffman et al., 1995).

- It is based on the assumption that the primary vectors of pollen in apple orchards are honey bees (Free, 1970; Crane and Walker, 1984).
- Based on weather conditions in the orchard, the state of the flowers and the size of the potential honey bee population, it then computes a prediction of the numbers of bees foraging and the potential amounts of pollen transferred.
- Weather conditions after pollen transfer and the age of the flowers then determine how many flowers will be fertilised successfully (see Dennis, 1979).
- This model has the ability to run simulations with varieties not included in the programme (i.e. Golden Delicious, Delicious and Granny Smith) by entering their bloom parameter values through menus. It also has a day degree calculator.

**Supplementing pollen supply in the orchard using floral bouquets**

In some seasons flowering of the pollinating varieties in an apple orchard may be insufficient to guarantee set of an optimum crop. This may be a consistent seasonal problem, possibly due to there being inadequate numbers of pollinators planted in the orchard.

- More often, the problem only occurs in one season and is caused by the pollinators failing to flower adequately or in synchrony with the main variety.
- Biennial bearing is a frequent cause of poor flowering on some varieties used as pollinators.
- One temporary solution to this problem is to cut flowering branches from another orchard containing suitable pollinating varieties and introduce these to the affected orchard as ‘bouquets’.
- The branches are placed in large buckets of water between the trees and in the tree rows.

**Supplementing pollen supply in the orchard by grafting**

Where the problem of inadequate pollination is a more permanent one, whole or part trees of the main variety can be grafted over to a pollinating variety using frame working or top working grafting techniques (see Garner, 1983).

- Work conducted at Long Ashton Research Station showed that Malus species could perform well when grafted as branches into trees of the cropping variety (Williams, 1976).
- If the trees of the main cropping apple variety are suspected as being virus infected, grafts of Golden Hornet or Winter Gold should not be used, as they are very virus sensitive.
- In these situations, it is possible to use the less sensitive Malus aldenhamensis and Malus Hillieri.
- When grafting crab apple pollinators into trees of the main commercial variety, it is essential to control the vigour of the latter in the first few years, so as to allow the graft to develop without too strong competition.
- Grafts should be placed in a dominant position on the tree.
- Once established the grafted crab can compete with the main variety quite effectively.
- Indeed, M. aldenhamensis and M. Hillieri frequently prove to be very strong growers as grafts.
- Grafting other fruiting apple varieties into trees of the main variety (e.g. James Grieve grafted into Cox) can also prove effective in pollination.
- However, there is seldom sufficient time to pick the pollinating branch and failure to do this can depress flowering in the subsequent year.
- Also, unless great care is exercised it is very easy to remove the branch during winter pruning (Williams, 1966).
Pollen compatibility

Most diploid apple varieties are cross compatible (i.e. self-incompatible). This means that they will not set fruit with their own pollen in most environmental conditions.

- They require the viable pollen of another variety to be transferred to their receptive stigmas and the subsequent germination and growth of this pollen down the style to the ovary.
- Once there, it should be able to grow, albeit relatively slowly, into the micropyle of an ovule and effect fertilisation.

However, some apple varieties are wholly or partially cross incompatible with each other.

- This has been attributed to a multi-allelic gametophytic locus S.
- In instances of cross incompatibility, the pollen grains germinate but their growth is arrested in the top one third of the style; this is known as gametophytic incompatibility.

Early work (Kobel et al., 1939) showed that by making various possible cross pollinations and observing the speed of pollen tube growth down the style it was possible to distinguish between compatible, semi-compatible (partially compatible) and incompatible crosses. On the basis of this work, S alleles were assigned to some 20 different cultivars.

Further research (Broohaerts et al., 1995; Jannesens et al., 1995) isolated cDNAs responsible for the stylar ribonucleases associated with some of the S alleles first mentioned by Kobel et al.

- This led to the development of a molecular diagnostic technique for the identification of these alleles based on allele-specific PCR amplification and restriction digestion.

Recent research at East Malling (Bošković and Tobutt, 1999) has extended this work and characterised the S alleles in a range (56) of diploid and triploid apple varieties based on their stylar ribonucleases.

- Diploid varieties with the same pair of S alleles are in most instances incompatible with each other.
- Where the two varieties share one S allele in common, then only 50% of the pollen produced will be capable of germination and growth down the style to fertilise the ovule.
- This is known as partial compatibility or semi compatibility.

Self fertile clones of the apple varieties Cox’s Orange Pippin and Queen Cox have been produced using irradiation techniques of fruit breeding.

- These clones produce less viable pollen than their self-incompatible parents but are capable of setting fruits with this pollen and with no requirement for the planting of other pollinating varieties in the orchard.
- Work by Petropoulou (1985) showed increased stylar receptivity in two of these self-fertile clones of Cox and the author concluded that this may be due to mutations at loci controlling stylar receptivity rather than at the S incompatibility locus.

Research in Switzerland (Kellerhals and Wirthner-Christinet, 1996) showed that hand pollination of Gala with its own pollen followed by cross pollination, using Spartan pollen, 24 hours later led to poor fruit set.

- The initial setting in some way inhibited fertilisation by the Spartan pollen.
- It is not known whether this could have a role to play in poor fruit set observed with open pollination in the orchard.

Testing pollen compatibility

Growers wishing to test compatibility of varieties in the field can adopt the following simple method:

- Collect flowers of the variety chosen to provide pollen 24 hours before the planned pollination.
- Choose flowers at the balloon stage and remove petals before placing on trays at room temperature.
- On the tree to be pollinated choose and tag representative branches of a horizontal or semi-horizontal and similar orientation and height above ground level.
- Remove petals from the chosen flowers on the spur buds at the balloon stage; this makes them unattractive to pollinating insects.
- Remove surplus flowers from 25 spaced clusters to leave 4 flowers/cluster; remove the king flower and any potentially late opening flowers.
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- On the tree to be pollinated choose and tag representative branches of a horizontal or semi-horizontal and similar orientation and height above ground level.
- Remove petals from the chosen flowers on the spur buds at the balloon stage; this makes them unattractive to pollinating insects.
- Remove surplus flowers from 25 spaced clusters to leave 4 flowers/cluster; remove the king flower and any potentially late opening flowers.
- Thoroughly brush the stigmas with the anthers of the pollinating variety.
- Ideally, each flower is pollinated twice, once at the time of anthesis (flower opening) and again two days later.
- The reason for pollinating twice is to take advantage of the phenomenon known as ‘pioneer pollen’.

The above technique does not entirely exclude the possibility of cross pollination but it can give a quick idea of pollen compatibility.

- A modified strategy, used in the Netherlands, involves no removal of petals and only one pollination at the time of flower opening (anthesis) (Wertheim).
- Cross pollination is prevented by putting a very small dab of vaseline on the stigmas after they have been hand pollinated.

Pioneer and mentor pollen effects

According to Dutch research (Visser and Verhaegh, 1980), the application of compatible pollen twice with a one to two day interval between applications, could stimulate the activity of the pollen applied on the second occasion.

- This was thought to be due to some action by the first applied pollen, thereafter called the ‘pioneer pollen’.
- This phenomenon has been used in attempts by plant breeders to overcome self-incompatibility by applying compatible pollen from another variety first, followed by self pollen one to two days later (Visser et al., 1983).

Research conducted in Russia many years ago showed that whilst self pollen generally grew poorly on apples, its addition to pollen from another compatible variety on the stigma, actually helped fruit set and the number of seeds in the fruits (Nesterov, 1956).

In further work conducted in the Netherlands (Visser and Oost, 1962), combinations of self-incompatible pollen with viable but sterile (irradiated) compatible pollen were shown to be effective in overcoming self-incompatibility and this phenomenon came to be known as the ‘Mentor Pollen’ effect.

However, more recent studies in Switzerland (Kellerhals and Wirthner-Christinet, 1996) have shown that double pollination of Gala or Elstar, first with self pollen and secondly with compatible pollen one day later, inhibited the growth of the compatible pollen.
It is possible that the contribution of self pollen to fruit set in apple is greater than previously thought.

If combined with warm weather conditions and some cross compatible pollen, the self pollen may play a significant contribution to fruit set and seed numbers in some situations.

**Pollen quality (viability)**

It is essential that the pollen grains moved by insect vectors, wind or artificially by man, between the pollen donor (pollinating variety) and the main commercial variety, remain viable and capable of germination and growth down to the ovary and micropyle of the ovule.

- Pollen viability can be judged crudely by examining the grains under a low powered light microscope.
- Small shrunk grain is not viable.
- Many of these are found in the pollen collected from triploid varieties of apple.
- The self fertile clones of Cox and Queen Cox also produce a significant proportion of pollen that is small, shrunk and not viable.

A more accurate assessment of pollen viability can be carried out using germination tests on artificial media, such as agar or sugar solutions. Sometimes staining procedures are also used to estimate pollen viability (Seelhemer and Stösser, 1962).

- Growers wishing to store pollen for use in hand pollination in the subsequent season can achieve this by placing the pollen in a sealed desiccating jar in a refrigerator.
- Very long-term storage (e.g. 10 years) is possible at -20°C and reduced pressure.
- Aborted pollen grains are common in the self fertile clones of Cox’s Orange Pippin and Queen Cox but may also occur in other varieties in some seasons (Gagnieu, 1947).
- This may be due to faulty reduction division from the diploid to the haploid.
- High temperatures (not common in the UK) can increase the amount of aborted pollen produced.

It should be noted that the anthers of some cider varieties are unable to release their pollen resulting in a form of male sterility.

**Dormancy and synchrony of flowering times**

For effective transfer of viable pollen its growth and the fertilisation of the ovule, it is essential that, where cross-pollination is required, the two varieties flower at approximately the same period.

- At the very least there needs to be an overlap of several days in the flowering periods of the main and pollinating varieties.
- Scion varieties of apple differ in their dormancy characteristics and this can, on occasions, influence the synchrony of flowering between the main variety and its pollinators.

**Dormancy and chilling requirements**

The timing of bud break and flower opening is influenced by the dormancy characteristics of the scion varieties and the climatic conditions in late autumn, winter and early spring.

- For effective bud break and flowering, flower buds of apples require a period of chilling to break dormancy, followed by a period of higher temperatures (forcing temperatures) to enable the flowers to complete their development and open.
- In areas where winters are normally too warm as in the tropics, apples can only be grown at higher altitudes (e.g. above 1,000 metres).
- For most varieties, 1,000 hours of temperatures of 7°C-8°C or less are required to fulfil their chilling requirement (Kronenberg, 1979 see Further reading).
- If this requirement is fully satisfied, the buds will develop and flower normally, if given suitable forcing temperatures.
- Where this requirement is only partially met, then flowering may prove erratic and flower quality be lessened.
- The figure of 1,000 hours at temperatures of less than 7°C is somewhat arbitrary and some geographic locations where apples grow quite successfully (Napoli, Rome, Pisa and Barcelona) often fail to record this total of chilling units.
- In most parts of the UK, the chilling requirements should be satisfied usually by mid-January in and around the south east of England.
- Global warming in the future could influence the date at which the chilling requirement is satisfied for apples grown in the UK. Further studies are warranted on this possibility and its implications to UK apple yields.

**Synchrony of flowering necessary for effective fruit set**

Apple scion varieties have been classified, rather crudely, on the basis of their average flowering dates recorded over several seasons. Varieties are often grouped into those flowering early, mid-season or late (Dalbro, 1966; Way, 1978).

- One of the problems affecting growers wishing to choose suitable pollinating varieties is that varieties have been grouped according to their average date of flowering.
- Even when the full range of flowering dates are given, as in the information recorded in the fruit trials at Brogdale, Kent, these ranges do not represent the actual length of flowering periods in every year.
- This means that, whilst sufficient overlap of flowering dates of two varieties may occur in many years, it does not necessarily occur in every year, especially when varieties from early and mid-season, or mid-season and late groupings are planted with the aim of mutual pollination.

Research in Denmark (Grauslund, 1996) has shown that the 10 year average length of flowering periods for 11 apple varieties was 16 days.

- Advice in the Netherlands (Kemp and Wertheim, 1992) is that the average flowering ranges of any two varieties should overlap by a minimum of six days.
- However, the Danish research showed that even when the overlap was 11 days it was not always ideal in every year.
- This is because many of the first flowers to open on a variety are those with the best setting and fruit growth potential.
- If, for instance, a late flowering variety has been planted as a pollinator in a block of a mid-season flowering variety, it is unlikely that many of the flowers opening first on the mid-season variety will receive adequate pollination in sufficient time to set fruits.
- If the mid-season variety also produces flowers with short EPPs (like Cox), the problem is exacerbated.

**Models for predicting apple flowering dates**

Attempts in the Netherlands to develop a model for predicting flowering dates of apple were only partially successful (Kronenberg, 1983; Kronenberg, 1985) and further work.
Pollen of some scion varieties germinates and grows down the receptor styles of flowers at quite low temperatures, compared with the standard clones of Cox or Queen Cox. The self-fertile clones of Cox’s Orange Pippin (Cox Self-fertile Clone 8) and Queen Cox (Queen Cox Self-Fertile Clone 18) both produce low proportions of viable pollen under which the pollen will germinate. Apple scion varieties differ in the proportion of viable pollen produced, the average germination percentages achieved (over a number of seasons) and the climatic conditions influencing fertilisation. The most important of these are:

- The apple scion variety
- Pollen quality
- The quantity of pollen on the stigma
- Pollen compatibility
- Climatic conditions

Factors influencing fertilisation

Pollen germination, its growth down the style into the ovary and the achievement of fertilisation, by the pollen’s entry into the micropyle of the ovule, are influenced by a number of factors. The apple scion variety, pollen quality, and climatic conditions are the most important of these:

- The apple scion variety
- Pollen quality
- The quantity of pollen on the stigma
- Pollen compatibility
- Climatic conditions

Apple scion variety

Apple scion varieties differ in the proportion of viable pollen produced, the average germination percentages achieved (over a number of seasons) and the climatic conditions under which the pollen will germinate.

The self-fertile clones of Cox’s Orange Pippin (Cox Self-fertile Clone 8) and Queen Cox (Queen Cox Self-Fertile Clone 18) both produce low proportions of viable pollen compared with the standard clones of Cox or Queen Cox.

- Much of the pollen produced by these self-fertile clones is aborted and infertile.
- Whilst this has little consequence when the self-fertile clones are planted as monocultures (i.e., solid orchard plantings of the same clone), their use as pollinators in other orchards of self-sterile clones or varieties cannot be recommended.
- Insufficient viable pollen is produced by these self-fertile varieties to be collected and transported efficiently by insects between flowers on different trees.

Factors influencing pollen germination and pollen tube growth down the style

- In favourable conditions, pollen grains deposited on the stigma become hydrated (take up water) and subsequently germinate.
- The pollen tube emerges through one of the three germ pores and grows into the papillose epidermis on the stigma.
- After it penetrates the stigmatic surface between the papillae, the pollen tube enters the connecting tissue within the style.
- Starch in this transmitting tissue is used as a food source by the extending pollen tube.
- The tubes usually take two to four days to grow to the base of the style, but this is very dependent upon ambient temperatures.
- At temperatures of 5-10°C pollen tube growth is very slow.
- Not all of the germinating pollen grains reach the base of the style.
- If approximately 50 germinate and start to grow down the style only five or ten pollen tubes make it to the base.
- At the base of the style the pollen tube must penetrate the pericarp before entering the ovule.
- Although a very short distance, this penetration can be quite slow.
- For example whilst pollen grains may take only two to three days to germinate and reach the base of the style, they may take a further six to eight days to transverse the pericarp and effect a union with the ovule.
- Although the distances within the pericarp are less than down the style, the conducting tissues located in the latter are much more favourable for rapid growth (Stösser et al., 1996).
- Once in the locale of the ovary, pollen tubes frequently show very little directed growth towards the micropyle of the ovule and may ramify for more than a day before locating and penetrating the micropyle (Stösser, 1986).

Research at Long Ashton Research Station also endeavoured to develop a model for apple fruit bud development and hence time of flowering (Landsberg, 1974).
Quantity of pollen on the stigma

There is evidence with many flowering plants that the quantity of pollen deposited on the stigma influences its subsequent germination (Brewbaker and Majumdar, 1961).

- Increasing the number of grains deposited on the stigmatic surface is thought to have a mutually stimulatory effect on grain germination, possibly attributable to the increased calcium ions associated with increased pollen abundance (Brewbaker and Kwack, 1963).

Climatic conditions

- The ideal climatic conditions for pollen germination and growth are temperatures between 15°C and 25°C, no rain, and minimal or no desiccating winds.
- At lower temperatures pollen germination and growth will be slower.
- Very little pollen germination occurs at temperatures less than 10°C.

Fertilisation and fruit set

- Once the pollen tube has located and penetrated the micropyle and fused with the embryo sac, fertilisation has taken place.
- Pollen grains of apples contain two nuclei, which move with the cytoplasm in the pollen tube as it moves down the style.
- At some point one of these nuclei (known as the vegetative nucleus) degenerates and the second one (the generative nucleus) divides into two sperm nuclei.
- When a single pollen tube enters the micropyle it discharges the sperm nucleus into the embryo sac.
- One of these nuclei fertilises the egg to form the zygote (embryo).
- The other unites with the two polar nuclei in the ovule to form the triploid endosperm tissue.

Induction of fruit set and retention with plant growth regulating chemicals

Researchers have for more than 30 years sought to improve the fruit set and retention of apples, using sprays of various plant growth regulating chemicals. The principal ones tested have been

- Auxins
- Auxin transport inhibitors
- Gibberellins
- Gibberellin biosynthesis inhibitors
- Cytokinins
- Mixtures of auxins, gibberellins and cytokinins
- Ethylene biosynthesis inhibitors
- Polyamines

Auxins

Attempts to improve apple pollination and fruit set with sprays of auxins, such as IAA and NAA have proved ineffective.

- However, when combined with gibberellins (GA₃ or GA₄+7), auxins such as NAA, NAAm and 2,4,5-TP have proved effective in increasing fruit set (see below).
- Although auxins such as IAA are strongly implicated in the processes associated with fruit set and retention, sprays of IAA are largely ineffective in improving fruit set.
- One of the contributory reasons for this may be the high instability of IAA, when dissolved in aqueous solutions and sprayed onto trees.

Auxin transport inhibitors

Attempts by researchers at Long Ashton Research Station to increase fruit set on several tip or spur bearing apple varieties, using sprays of 2,3,5-tri-iodobenzoic acid (TIBA) at 150 ppm, were unsuccessful.

- The only effect of the sprays was to reduce fruit size at harvest.

Gibberellins

Gibberrellins have been shown to be an essential hormone if parthenocarpic fruit set is to be induced in apple (Schwabe and Mills, 1981).

- However, they are largely ineffective used alone on varieties such as Golden Delicious, Jonagold, Cox's Orange Pippin and Boskoop (Wertheim, 1993; Varga, 1966).
- Research in Germany over a period of 10 years showed that sprays of either GA₃ or GA₄+7 to frost-affected flowers had no significant effect on fruit set (Bangerth and Schröder, 1994).
- Studies conducted in Canada (Looney et al., 1985) suggested that whilst GA₃ and GA₇ had inhibitory effects on apple flower initiation, GA₄ had a stimulatory effect.
- These results could not be repeated, however, in German experiments (Bangerth and Schröder, 1994).

Gibberellin biosynthesis inhibitors

Trials with daminozide (SADH or Alar) in the early 1970s showed that, not only did the sprays increase flowering on trees of Discovery in the year after spraying, they also stimulated pollen tube growth in the styles of the flowers produced (Stott et al., 1973; Stott, et al., 1974).

- Alar is no longer available for use on fruit trees.

Cytokinins

- Treatments of apple flowers with cytokinins on their own do not induce fruit set.
- However, in combination with gibberellins stable cytokinin-type compounds such as diphenylurea or CPPU can have beneficial effects on fruit set and yields.

Mixtures of auxins, gibberellins and cytokinins

Research conducted in the 1960s in the USA (Williams and Letham, 1969) first showed that combinations of gibberellins with cytokinins might have promise as setting agents for apples.

- The 'Wye Mixture', developed by researchers based at Wye College in Kent, enjoyed some popularity in the 1970s and early 1980s as a fruit setting spray for use...
Recent studies by Goldvin and colleagues demonstrated the feasibility of inducing pantherocarpic (seedless) fruit set in the apple variety Cox’s Orange Pippin. It had been known for many years that low concentration, high volume sprays of gibberellic acid GA3 could have a very beneficial effect on pantherocarpic fruit set. Applied following severe frost-damage to flowers, the sprays stimulated the production of a crop of pantherocarpic fruits.

Trials on apples using GA3 sprays with no other hormones added were not successful, however, when applied after frost damage. The work conducted at Wye College demonstrated that, if the GA3 (200 ppm) was supplemented by an auxin and a ‘cytokinin’, the spray mixture was capable of inducing good fruit set.

Various auxins were tested including 1-naphthaleneacetic acid (NAA), 2-naphthoxyacetic acid (NDAA at 50 ppm) and 2,4,5-trichlorophenoxycetic acid (2,4,5TP at 10 ppm) and although there were small variations in response all seemed to work well with the other two components of the mixtures.

The cytokinin used was not a true cytokinin, but a product known to have cytokinin type activity in plants, namely N(1H)phenylurea (CPU at 300 ppm).

Trials in Germany, however, (Bangerth and Schröder, 1994) showed no consistent benefits when using this Wye Mixture on varieties such as Golden Delicious, Jonagold and Boskoop.

Trials in the USA (Greene, 1980) have also shown that applications of gibberellins plus 6-benzylaminopurine (a cytokinin) caused reduced rather than improved fruit set and this was attributed to increased ethylene levels induced in the flowers by the sprays.

Blasco et al., (1982) showed that whilst sprays of the Wye Mixture increased fruit set of Cox trees on M9 rootstock, no similar effects were recorded on trees on M26, M7 and MM106 rootstocks.

However, initial fruit set was increased on trees on all rootstocks, irrespective of their vigour.

It is hypothesised that the sprays facilitate the retention of fruitlets, which have initially set with few seeds.

Later in the season, when competition for assimilates with extension shoots increases, these fruits are shed from the trees on the more invigorating rootstocks.

On M9, where shoot competition is less, they are retained.

Intuitively, if this hypothesis is correct, one would expect treatment with chemicals which reduce excessive shoot growth to aid the retention of hormone-stimulated fruitlets on trees grafted on invigorating rootstocks.

However, as most of the growth retardant chemicals currently available reduce natural gibberellin levels in the tree (e.g. Cultar and Regalis), they are likely to partially negate the value of the gibberellins in the setting mixtures.

According to Bangerth and Schröder (1994), the best effects are achieved with cytokinins which are biologically stable such as the phenyl urea type and natural cytokinins such as zeatin-riboside give poorer results.

In these trials, the best cytokinin type compound was N(2-chloro-4-pyridyl)-N-phenylurea (CPU) at 20 ppm.

The best combinations were of GA3 or GA4 (100 ppm) together with CPU GA3 and GA4 gave poorer results.

It is hypothesised that the effects are brought about by the hormones’ direct action on the fruit ovary and not by any changes in fruit ‘sink strength’.

It is possible that a short hormone pulse, provided by the treatments, establishes hormone autonomy in the unfertilised ovary (Browning, 1989).

The addition of the cytokinin may enable this hormone autonomy to be sustained through until harvest.

It is interesting that fruits set using this mixture are not susceptible to abscission induced by seeded fruits or strong shoot growth close by.

In other crops such as lski fruits, CPU causes a reduction in the natural levels of the inhibitor ABA.

Unfortunately, the GA + CPU mixtures used in the trials described above reduced flowering significantly in the subsequent season.

Also, the CPU in these mixtures causes russetting and flattening of the fruit shape. Because of this and because registration may prove difficult, it is unlikely that these gibberellin CPU mixtures will become available to growers in the near future.

One recent suggestion is that neither the gibberellins nor the cytokinins have a direct inhibitory effect on flower initiation, but it is the increased fruit set induced by them that inhibits subsequent flowering (Bangerth and Schröder, 1994).

**Ethylene biosynthesis inhibitors**

Ethylene is involved in the abscission of flowers and young fruitlets and application of chemicals that inhibit ethylene production by the apple tree can sometimes reduce flower and fruitlet abscission.

- Aminoethoxyvinylglycine (AVG) has been reported to inhibit both ethylene production (Baker et al., 1978) and its action (Beyer, 1976); AVG inhibits the enzyme system that converts 3-adeninylmethione to 1-aminoacyclopropene-1-carboxylic acid.
- This same enzyme system is also influenced by the endogenous levels of auxin (IAA) in the fruits and spurts.

Sprays of 200 ppm AVG applied at bloom time to Red Delicious apple trees increased fruit set but reduced fruit size and increased the length diameter ratio of fruits at harvest time (Greene, 1980).

- In further studies Greene (1983a) showed that sprays at 500 ppm under harvest increased the initial but not the final set in the subsequent season of McIntosh, Spartan and Spencer apple trees grown in Massachusetts.
- Two clones of the variety Red Delicious also responded similarly, but here the treatments increased final as well as initial set.
- However, final fruit sizes were reduced by the treatments (10% to 20%) and the length diameter ratios of the fruits were increased.
- Applications of fruit thinners were shown to be ineffective in reversing the negative influence of AVG on fruit sizes (Greene, 1983b).
- It has been argued that the increase in fruit set achieved with the autumn AVG treatments is due to reduced post petal fall abscission of very young fruitlets (Williams, 1981).
- Williams also showed that the AVG treatments suppressed ethylene production in the leaf buds and induced increases in bud break vegetative growth.

Trials conducted in the early 1980s at Long Ashton Research Station (Child et al., 1986) showed that sprays of AVG at 250 ppm applied at full bloom increased the initial and final fruit set of Cox’s Orange Pippin apple trees.

- The AVG inhibited the ethylene produced following treatment with gibberellins but had no effect on the ethylene induced by treatments with the thinner NAA.

Other known inhibitors of ethylene production by the tree, such as aminoxyacetic acid and silver nitrate have generally proved ineffective in increasing apple fruit set (Dennis et al., 1983; Reihert et al., 1997).

Recent studies by Reihert et al., (1997) led the authors to suggest that differences in ethylene evolution are not responsible for differences in initial fruit set.

- They argued that the effects of AVG in increasing set are independent of its effects on ethylene evolution.
In earlier work, UK scientists had suggested that the AVG sprays delayed the senescence of ovules and increased the setting capacity of older flowers (Child et al., 1982).

**Polyamines**

Sprays of the aliphatic polyamines, spermine, spermidine and putrescine, have been shown to increase the retention of very young fruits on apple trees (Costa and Bagni, 1983).

However trials conducted at HR-East Malling gave disappointing results with these spray treatments (Knight, personal communication).

**Branch orientation and its effect on fruit set and retention**

Research conducted at HR-East Malling in the 1980s (Robbie et al., 1993) showed that training branches of the variety Cox’s Orange Pippin to the horizontal during August, produced flowers that gave better fruit set in the subsequent year than flowers on branches trained to the vertical.

- However, if branches trained to the vertical in August were subsequently trained to the horizontal in the following April, during flowering, then fruit set on these was also greatly improved.
- This indicates that the horizontal orientation is important not just to flower development but to the success of pollination/fertilisation itself.
- The failure of poor fruit set on vertically orientated shoots was not attributable to more vigorous shoot growth and competition between shoots and flowers for assimilates, minerals and water.
- Flowers on vertical shoots with all the competing shoot growth removed still set poorly.
- The studies also showed that the spurs and flowers on vertically and horizontally orientated branches did not differ in their mineral content or the ability of the primary leaves to acquire carbon and morphologically the flowers from the two branch types were similar.
- In a way that is not understood, training branches to the horizontal appeared to increase the proportion of healthy ovules in the flowers at anthesis (flower opening) and later.
- Increases in ovule fertility and associated increases in the Effective Pollination Periods (EPPs) of flowers from horizontally orientated flowers were evident, even in flowers on branches moved to the horizontal close to flowering time.

**Vigour of shoot growth and its effect on fruit set and retention**

Research at Long Ashton showed that management of apple trees that results in excessive growth of bourse or extension shoots can reduce fruit set (Abbott, 1960).

- The reasons for this are probably primarily associated with competition between the shoots and the young fruitlets for assimilates and minerals, although hormones produced by the shoots may also play a role in this effect.
- Management practices, which reduce the vigour of shoot growth, generally result in improved fruitlet retention.
- Whilst initial bourse shoot growth may compete with fruitlets and cause fruitlet abscission, bourse shoots aid fruitlet growth later in the season, possibly by supplementing the supplies of available assimilates.

**The effect of irrigation and water supply to the tree on fruit set and retention**

Trees grown in droughty situations show significant reductions in shoot growth, leaf area and yields (Jones and Higgs, 1985; Jones et al., 1983; Lakso, 1983).

- However, experiments in Germany showed that the numbers of flowers formed per inflorescence (cluster) or the fruit set per linear branch length were not reduced (Sritharan and Lenc).
- The reduced yields must be mainly attributable to reductions in tree size or to reductions in fruit size.