Sustainable Cider Apple Production

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SEPTEMBER 2011

Acknowledgements

We would like to thank Richard Heathcote, Liz Copas and Chris Turnbull for their help and advice.

MANAGEMENT SUMMARY

The cider apple orchard of the future needs to be sustainable, resilient to environmental and ecological challenges, with reduced pesticide inputs; these characteristics need to be achieved with minimal negative impact on yield and fruit quality. Areas that offer opportunities for sustainable orcharding include: 1) use of cover crops to provide an environment conducive to beneficial insects; 2) management of pests and diseases using alternatives to chemical control approaches [e.g. use of ground cover plants, resistant varieties, sanitation measures (leaf litter management), use of particle films, plant extracts, viruses, bacteria, reservoirs of natural enemies, and IT based advisory systems such as ADEM^{TM} and SOPRA]; 3) minimization and effective management of waste. Major waste products of an orchard are prunings and trash, and apple pomace. Pruning waste has been found to be rich in polyphenols; a potential use for the extracted polyphenolics has been proposed to be in the food industry, as natural antioxidants. Another alternative use of pruning waste is as a renewable source for energy production or as a soil amendment, a biochar.

There is increasing evidence that global climate change is taking place. This is likely to lead over the coming years to reduced winter chilling, altered flowering periods (and activities of pollinators), high temperature and drought stress at times during the fruit swelling period (June - September), and altered harvest dates. New varieties will therefore be needed which are better adapted to a changed climate. Generating new selections from crosses between low chill varieties and valued cider varieties is a logical approach for future breeding programmes. To avoid potentially negative effects on fruit set of pollinator disruption, the self-fertility of some cider apple varieties could also be exploited. This character needs to be better studied and understood – what are its causes, how consistent is it (e.g. year-on-year), how is it inherited. Other breeding objectives include reduction of biennial bearing and enhanced polyphenol content of fruit.

Looking forward, there are two clear options for cider orchards. The main focus of the first one is intensification, a process which has begun in many cider orchards over the past several decades. The establishment of such systems requires smaller trees, planted and managed in arrangements which allow maximum light interception as well as maintenance and harvesting of the crop with minimum labour input. Current intensive systems adopted in cider orchards probably do not achieve maximum light interception since priority is given to ease of harvesting.

There are opportunities for further development here, including, possibly, the use of robotics.The vision here is of an orchard system which establishes quickly, comes into bearing early, optimizes light interception and reduces as far as practical alleyway space. The need for large alleyways to allow access for machinery could be minimized by the use of a new generation of small, self-navigating, robotic machinery which would largely operate below closed canopies, carrying out maintenance operations such as routine application of pesticides from below rather than from the side or above. In the intensive system, ecosystem sustainability may be best addressed through an area around the orchard periphery designed to maximize beneficial insects.

The second option is a more extensive orchard system in which ecosystem services are provided over the whole orchard. The vision here is for a low maintenance orchard system, with a cover crop grown to provide pollen and a habitat for pollinating and beneficial insects. Many potential cover crop species exist which could contribute to biologically rich ecosystems. Intercropping and grazing are options for this system.

Whatever the planting system (extensive or intensive), certain generic approaches can be adopted. The use of pruning waste and trash, and pomace as sources of health-beneficial polyphenolics is one such area. The use of pruning waste and trash to generate biochar is another; biochar could contribute to orchard soil condition.

Focused research is needed to build on the opportunities identified here; in many cases the objective would be to adapt findings from other countries/environments to the UK situation. For example, further research is required to identify which plant species are optimal in terms of nectar and pollen source for foraging insects, in order that their populations are maintained outside periods of pest activity. The conditions providing optimal refuges for ground dwelling invertebrates need to be established. It is likely that recommendations will need to be tailored to individual parts of the country, particularly with regard to mitigation of the effects of climate change. More strategic is the development of cider apple breeding for the UK, to address fruit quality needs in trees able to grow productively under conditions of predicted climate change.

Overall, the recent success of the cider apple industry makes worthwile the effort to develop sustainable production systems which take account of grower situation, market, and environment. This development must be underpinned by a strategic breeding programme for the long-term success of UK cider apple production.

Abstract

The cider apple orchard of the future needs to be sustainable and resilient with reduced pesticide dependence. These characteristics need to be achieved without any adverse effects on fruit yield and quality where possible. This report considers the orchard from an ecosystem point of view where practices such as habitat management (e.g. use of cover crops, artificial weed strips, pollen and nectar sources), grazing, and intercropping could maximize the ecosystem services. It also considers other aspects of the orchard such as minimization and effective management of orchard waste including pruning waste, empty agrochemical containers and apple pomace, as well as integrated pest and disease control based on minimal pesticide input, which have the potential to contribute to sustainable orcharding. The development of new varieties suitable for climate change mitigation and with optimized fruit quality through new genetic techniques such as marker-assisted breeding is also discussed. This background information is synthesized into alternative visions for sustainable cider apple orcharding. General conclusions and proposals for implementation are presented.

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Part 1: The orchard system: a review of the literature

1.1 Introduction

The aim of this report is to review previous research in the field of cider apple production, and relevant related areas, in relation to the need for the cider apple orchard of the future to be sustainable, resilient to environmental and ecological challenges, with reduced pesticide inputs. These characteristics need to be achieved with minimal impact on yield, and improvement in fruit quality where possible.

We have laid out the report in three sections: the first considers the orchard in the broadest sense, describing the ecosystem services that can be offered, orchard designs which deliver both commercial and environmental outputs, and assessing the potential for waste reduction during cider apple production. We discuss varieties of cider apple in relation to the predicted impacts of climate change, the factors determining fruit quality, and the breeding opportunities offered by new techniques for genetic selection. The cider orchard ecosystem is also considered in relation to pest and disease problems and existing or potential methods of control which are consistent with the overall objective of sustainability.

In the second section we provide a synthesis of this information. We present alternative visions: optimized intensive production focused on maximum yield of quality fruit; and extensive production which is economically viable by virtue of the range of services it offers to the farm and the community. We suggest that both options are achievable and probably necessary, and that a hybrid between them may be the ideal: this delivers intensive production with areas offering ecosystem benefits. A third alternative, based on a ‘mixed farm’ approach is presented by way of contrast. The requirements to achieve these visions are discussed.

In the final section we summarize our conclusions and highlight knowledge gaps – areas where future research is needed. We make proposals for the implementation of new approaches to sustainable production, recognizing that for these to be successful the adoption of change management methods will be key. We suggest that foremost amongst these methods is the presentation of the concepts through demonstration plantings, and the provision of hard data (derived from rigorous research) in support of the alternative options.

As a preliminary, we define terms and present general background information.

The cider industry in the UK

The UK cider industry has been undergoing a renaissance in recent times, with the area of cider apple and perry pear production almost doubling over the last 15 years. In comparison, the UK has seen a decline in the area of dessert and culinary apple cultivation, albeit in part due to an intensification of production systems (Table 1, Appendix 1). This increase in cider and perry pear area is in order to meet an increasing UK consumption of cider, which itself contrasts with a falling demand for traditional beers. The UK is the largest cider producing country in the EU with volume share of 62% in 2008 (see Figure 1) (NACM, 2010). Approximately three quarters of the area of cider apple production is grown on more intensive bush orchard systems (the term 'bush' will be used to describe a central-leader tree in the context of the current review) whilst the remainder is produced on traditionally grown trees (DEFRA, 2010). Historically, cider apples were grown on a far wider scale than they are today; for example, in 1894, Somerset alone had 9,712 hectares of cider orchards (Legg, 1984). Even though there are hundreds of apple varieties selected as cider apples, all types of apples (culinary, dessert) can be used to make cider.

45% of all the apples grown in the UK are currently being used for cider making, with the quantity of cider produced being more than 600 million litres (NACM, 2010). According to NACM estimates there are a minimum of 480 cider makers in the UK with the majority of them found in the traditional cider making areas of Devon, Somerset, Gloucestershire, Herefordshire and Worcestershire (ukcider, 2011), and one of the two biggest producers (Bulmers-Heineken) being in Hereford with over 10,000 hectares of apple growing land (Heineken, 2010).

Table 1: Total area (hectares) covered by cider apples and perry pears, desert apples and culinary apples. Source DEFRA (2010). *provisional

YEAR	Cider Apples & Perry Pears	Total Dessert Apples	Total Culinary Apples
1985/86	3,417	12,771	7,066
1990/91	3,336	11,787	7,005
1995/96	3,453	8,849	5,594
2000/01	5,209	7,662	5,352
2005/06	6,551	5,505	3,860
2006/07	6,530	5,203	3,827
2007/08	6,290	4,873	3,797
2008/09	6,775	4,935	3,806
2009/10*	6,810	4,953	3,787

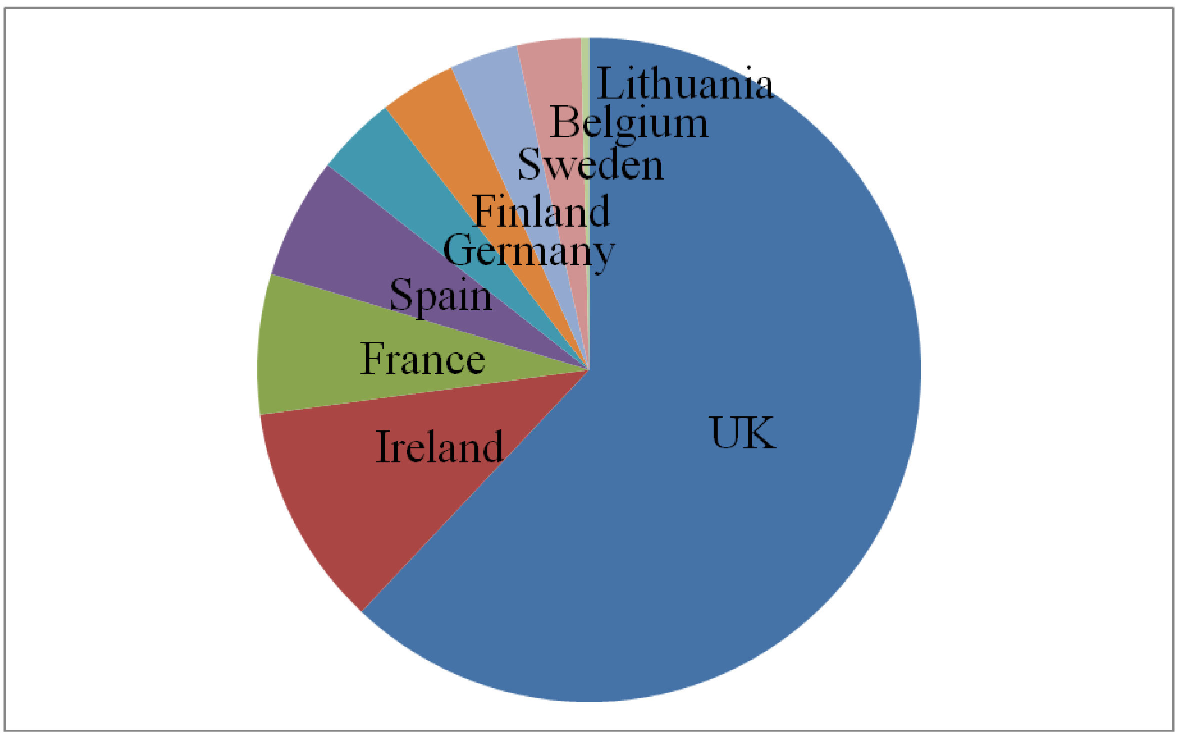

Fig. 1: The composition of cider apple production in Europe (NACM, 2010)

Sustainability

Sustainability is a much used word which stands for different things in different contexts. Cynics would say it has no precise meaning and is therefore without value. We think the essence of it is continuity – long-term thinking. Here is a definition in relation to economic development, taken from a key conservation publication:

A "sustainable economy" is the product of sustainable development. It maintains its natural resource base. It can continue to develop by adapting, and through improvements in knowledge, organization, technical efficiency, and wisdom (IUCN/UNEP/WWF, 1991).

For the present context, the important element is 'maintenance of the natural resource base'. This includes resources whose character is principally biological (pollinators and other beneficial insects, soil flora and fauna), chemical (water, nutrients through recycling, the carbon and nitrogen economies) or physical (soil structure, gaseous environment). Within the UK, sustainable farming is a key element of Defra's policy strategy and embraces five specific areas: - agriculture and climate change, sustainable water management, resource efficient and resilient food chain, sustainable farming systems and biodiversity, and plant health.

Pesticide usage in orchards is disproportionate to the area occupied. For example, although orchards in France constitute only 1% of the agricultural landscape, insecticide use accounts for 21% of sales with in excess of 30 treatments per annum. Likewise in the UK, pesticide use in cider orchards may be considerable, with on average 10 individual pesticides being applied in 2008 (Garthwaite *et al*., 2009). However, the environmental impact of pesticides and health concerns associated with chemical residues has led to EU legislation designed to restrict pesticide availability. In 2004, residues of eight fungicides in excess of maximum residue levels (MRL's) were detected in samples of UK apples, the most frequent being captan and carbendazim, together with the insecticide chlorpyrifos (Pennell, 2006). The use of carbendazim on apples was revoked in 2006. Adverse public perception concerning the presence of pesticide residues has contributed to a desire to achieve zero tolerance of pesticide residues in dessert apples. An innovative integrated pest and disease programme (IPDM) in which pesticides are not applied during fruit development has been successfully implemented at East Malling even with disease and pest susceptible varieties such as Cox and Fiesta (Cross and Berrie, 2008).

Nonetheless, the importance of cultivar selection has been highlighted in a comparative study of crop protection systems in France whereby pesticide usage was reduced by 43-56% for varieties with reduced scab susceptibility (Simon *et al*., 2011).

Although pesticides are designed to control undesirable species they may also have detrimental effects on non-target beneficial organisms and so reduce the potential effectiveness of biological control agents either directly or indirectly through loss of habitat. Furthermore, removal of vegetation with herbicides may cause pests to migrate to the crop (Van Emden and Williams, 1974). In a recent review, Simon *et al*. (2010) argue that reduced pesticide usage is essential for sustainable cropping systems, in particular those with high pesticide dependency such as orchards. Thus they assert that whereas simplified cultural practices can result in reduced biodiversity, perennial cropping systems may actually enhance biodiversity as a consequence of permanency, multi-strata design and adjacent plant management such as the provision of windbreaks. Orchards provide a range of strata from the understorey ground floor vegetation through the arboreal canopy thereby offering multi-strata habitats for predatory arthropods and insectivorous birds. Likewise, the inclusion of hedgerows (excluding species that host pests) and windbreaks reduces the uniformity of orchard design and provides additional habitat for beneficial species as evident from the negative correlation between aphids in orchard margins and greater incidence of predatory arthropods (Altieri & Schmidt, 1986a). Similarly, Rieux *et al*. (1999) reported that the presence of hedgerows increased the ratio of beneficial arthropods relative to phytophagous pests in pear orchards.

Ecosystem, ecosystem services, biodiversity

An ecosystem can be defined as the community of living organisms and their environment. Ecosystem services are resources provided by ecosystems on which human life depends, and include activities such as pollination and nutrient cycling, resources like food and fuel; and cultural benefits, for instance recreation and tourism, human health and well-being (Power, 2010). Sandhu *et al*. (2010) identify four types of ecosystem services, namely provisioning, supporting, regulating and cultural. An example of a provisioning service is biodiversity. Biodiversity is the species richness of an ecosystem or biological community. Provisioning services include pollination, biological control including weed seed predation, and carbon sequestration. Regulating services contribute to hydrological flow and nutrient cycling. In the context of the apple orchard, the ecosystem view implies consideration of the apple tree and those species which interact with it, and the physical environment including soil, air and nutrients. The orchard is an ecosystem devised and maintained by humans, but the same ideas can be applied to it as to more 'natural' ecosystems. A more thorough account of ecosystem services as relevant to orchard management is presented in Section 1.2.

Apples and cider apples: origins

The cultivated apple is derived from wild *Malus pumila* Mill., (also referred to as *Malus sieversii* (Ledeb.) Roem) and is itself also referred to as *Malus* x *domestica* Borkh. by some workers (see Mabberley *et al*., 2001; Luby, 2003). The origin of *M. pumila* is believed to be in central Asia, followed by gradual migration westwards over at least the past 5,000 years, with domestication occurring in parallel (Juniper and Mabberley, 2006). Escapes to hedgerows have meant that *M. pumila* can now be found wild in Britain, along with the indigenous crab apple, *M. sylvestris* (L.) Mill. The relationship of the traditional cider apple to domesticated dessert and culinary apples is not clearly understood. Cultural evidence, including the similarity of the cider apple press to the olive press has been suggested to indicate a possible more southerly, Mediterranean origin of the cider apple (French, 1982). There are also biological features of cider apples, including their high tannin content, and tendency to be self-fertile, which could suggest a different origin, perhaps with elements of *M. sylvestris* within their pedigree. However, although work is still ongoing at the time of writing, preliminary analysis of genetic diversity data from the apples within the National Fruit Collection at Brogdale, Kent, fails to find support for this theory and places the accessions held within the cider collection into a number of groups which also contain a range of the dessert varieties (Ordidge *et al*., unpublished). The issue is of potential importance in relation to future breeding efforts, given that the genetic base has been considered by some to be too narrow for long-term sustainability of dessert apple breeding (Noiton and Alspach, 1996). Steps have been taken to improve the potential diversity of the breeding gene pool by collecting wild *Malus* from its presumed centre of origin (Hokanson *et al.*, 1997); but the focus of worldwide breeding is on the dessert, not the cider apple. We return to this point in Section 1.5.

The biology of the apple tree and its annual cycle

The key events in the annual cycle of an apple tree are summarized in Figure 2. Although exact timings differ for different cultivars, the basic events are assumed to be similar amongst all of them. The onset of dormancy in the autumn is regulated by declining temperature, rather than photoperiod (Heide and Prestrud, 2005). Accumulated chilling is required to break dormancy, and once the chilling requirement has been fulfilled, the rate of spring bud growth is then determined by rising temperature. Hence, flowering time in the spring is a function both of winter cold and spring warmth, as well as genotype. The shedding of young fruitlets after flowering reaches a maximum in June, and is generally considered to be a mechanism by which the tree regulates its crop load, and one which is influenced by seed number within the fruit (Dennis, 1985). Vegetative growth declines in July and about the same time microscopic flower initiation begins in the buds; at this time fruits are also swelling, and within them seeds are maturing. Influential work by Chan and Cain (1967) suggested that production of the hormone gibberellic acid by the seeds exerts a critical inhibitory influence on flower initiation, accounting for the antagonism between fruit load and flower initiation which, if not managed, can lead to biennial bearing (a relatively common feature within cider varieties). Hence gibberellic acid spray programmes are now advocated to reduce biennial bearing in dessert apple production (e.g. Schmidt *et al*., 2009). At the time of fruit maturation and ripening during the autumn, the tree lays down starch in the trunk and roots. This provides a vital resource for renewed growth the following spring.

The overall picture of the annual developmental cycle of the apple tree is thus one of overlapping, as well as sequential processes. This leads to trade-offs, by which the tree ensures sustained growth over many years. The challenge for the grower is to manage these processes to optimize the timing of events within the cycle, and to minimize the competition which can lead to unbalanced cropping and/or poor tree growth. This management is achieved by spacing, training, pruning, fruit thinning and maintenance of appropriate nutritional status. We will consider these annual processes further in the context of varietal development for climate change mitigation.

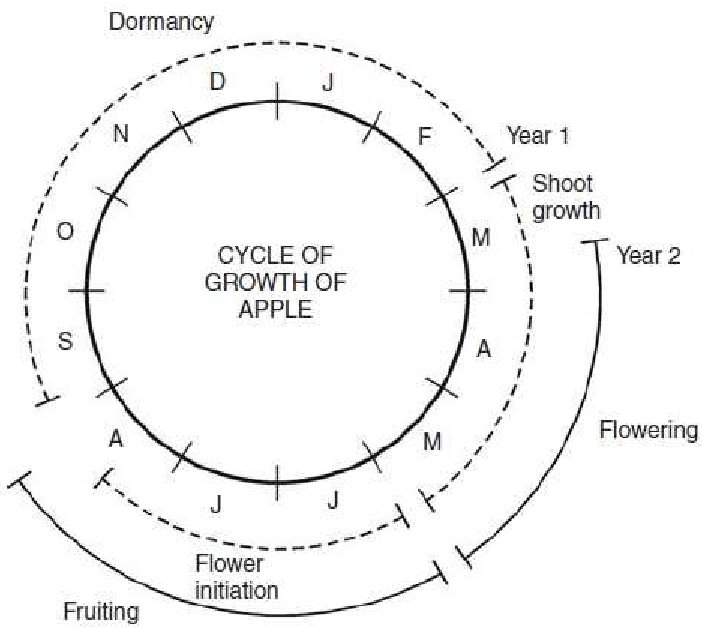

Fig. 2: The annual cycle of the apple tree

The planting system

Of all the decisions required to optimize the orchard, the planting system is arguably the most fundamental to long-term productivity. In a valuable survey of the research literature on apple planting systems, Robinson (2003) describes 28 planting systems, dividing these into four categories based on canopy shape: spherical, conic, flat planar, v-shaped. Spherical-shaped systems include the large globe-shaped trees of the early 20th century; the traditional cider orchard tree falls in this category. Citing the presence of the large, shaded, unproductive canopy core and the time taken for the tree and canopy to develop as key failures in this tree type, Robinson concludes that 'none of the current leading orchard systems is based upon a spherical canopy shape'.

Conic-shaped systems include the central-leader system with trees on a semi-vigorous rootstock, as well as the high-density slender-spindle, North Holland spindle, vertical-axis, SolAxe, and super-spindle systems with trees on dwarfing stocks. The typical modern cider orchard, with planting densities up to 750 trees/ha, is a central-leader system, which is relatively low density by modern dessert apple orchard standards. The advantages of the conic-shaped systems generally are that they comply with the natural form of the apple tree, and the conic form tends to give good light distribution in the canopy. As trees mature however, there is a tendency for the upper branches to shade out the lower canopy, a problem with the central-leader system that led Tustin and co-workers in New Zealand to develop the slender-pyramid system, in which large upper branches are not allowed to develop (Tustin, 2000). The fact that this can be used at relatively low densities with an MM106 rootstock (mature tree height approx. 4m) means that it could be relevant to cider apple production. It does, however, require a vertical trellis system. The general disadvantage of conic-shaped systems is that light is wasted on the alley areas. This can be overcome by having sufficiently tall trees (the typical cider apple tree solution), or by using close row spacing.

Of the other two systems (flat planar and V-shaped), the former are essentially espalier-type arrangements on trellises, and in modern orchards are associated mainly with dwarfed trees. Some of the principles behind one of the flat planar systems, the Solen (Lespinasse, 1989) could be of interest to cider growers planting the new, early harvesting cultivars obtained by crossing Michelin and Dabinett with early, tip-bearing James Grieve or Worcester Pearmain (see Copas, 2010). The Solen system was developed specifically for tip-bearers; it draws attention to the fact that the planting and training system must take account of tree habit. There are many V-shaped systems in modern dessert orchards, because of their high yields at maturity due to optimized light interception (Robinson and Lakso, 1991). Their use means that less light is wasted on the alley areas; the Geneva Y-trellis system (Figure 3) has also performed well in mechanical harvesting trials in the USA (Robinson *et al*., 1990). For these reasons, V-shaped systems may be of relevance in the drive for optimized cider apple production; their problem is high cost of establishment, and their typical association with dwarfing stocks and tree heights of not more than 2.5m. Most pertinent to the present context is the principle of training the tree at an angle to maximize light interception, and therefore yield. The opportunity that the tree support system offers for reduced wastage during mechanical harvesting is also of interest, but the focus of the reported trials was on dessert cultivars, where shake-catch harvesting was used, and the benefits were associated with reduced damage because less of the fruit fell through the tree on its way to the catcher (Robinson *et al*., 1990).

In the final analysis, growers need to optimize the efficiency of crop production and yield is a major determinant of that efficiency. The circumstances of cider apple production, in which there may be other goals, such as animal production or intercropping, may appear to make efficiency less crucial. In our opinion, however, identifying the most efficient orchard design is still a priority; and an efficient design is one in which net carbon uptake by the tree is optimized. This design may well not yet have been identified for cider apple production, and it will be cultivar-related. At least two different types of apple are used for cider production: traditional cider cultivars which may be moderately self-fertile, prone to bienniality, vigorous and mid to late season with more or less astringent fruit (the newer cultivars may be earlier season and possibly more likely to be tip-bearing); and dessert cultivars like Katy. Efficient orchard design is also related to harvesting system, capacity for initial investment, and orchard lifespan. Mechanical harvesting, in particular, needs to be efficient: it does matter if fruit are wasted, through damage, being left on the tree, or lack of quality. In Part 2 of this review we return to these points as we synthesize the information into visions of optimized and sustainable cider apple production.

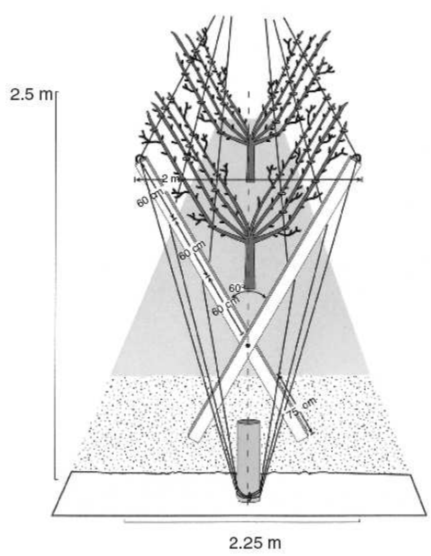

Fig. 3: The Geneva-Y-trellis tree (from Robinson, 2003)

1.2 Ecosystem services

Daily (1997) has defined ecosystem services as ‘the conditions and processes through which natural ecosystems and the species that make them up sustain and fulfil human life’. Maintenance of biodiversity, biological control of pests, diseases, and weeds are examples of these services (Costanza *et al*., 1997; Power, 2010) but there are also ecosystem dis-services that reduce productivity or increase production costs either directly as in the case of pests, or indirectly through competition for resources available in limited supply, such as weeds (Zhang *et al*., 2007; Power, 2010). Beneficial predatory polyphagous arthropods are an essential component of biological pest control, but their effectiveness can be constrained by insufficient pollen and nectar availability at various stages in their life cycles (Wäckers, 2004). Hence, the removal of ground floor vegetation within orchards can be detrimental to both pest management and pollination services. An alternative is to develop weed suppressive ground floras that are attractive to beneficial arthropods. However, care must be taken not to introduce species that are intrinsically competitive. Thus for example Wäckers identified *Aegopodium podograria* (ground elder) as the ideal pollen and nectar source for parasitic wasps, but such an intransigent species is unlikely to be attractive to UK growers. Surprisingly, the leguminous species *Medicago lupulina* and *Trifolium repens* failed to attract these parasitoids and in the case of *Trifolium pratense* and *Vicia sepium* actually repelled them. Nonetheless, leguminous cover crops within the tree row could offer the additional benefit of nitrogen fixation, possibly reducing competition between the crop and the alley. Recently, Storkey *et al*. (2011) reported empirical observations and model simulations of weed (*Chenopodium album*) suppression by eleven legume species in monospecific stands. The most suppressive species from field observations were *Medicago sativa* (lucerne), *Medicago lupulina* (black medick), *Lotus corniculatus* (bird’s-foot trefoil), *Onobrychis viciifolia* (sanfoin), *Trifolium incarnatum* (crimson clover) and *Melilotus alba* (white melilot). However, there was poor correlation between observed and predicted results in that whereas the simulation model predicted *Vicia sativa* to be one of most suppressive species it was found to be one of the least competitive species, despite being of similar height to *M. sativa*. Nonetheless, the authors predicted that tall growing species will recover more slowly after defoliation (mowing) as a consequence of greater loss of biomass as evident for *M. alba*. They concluded that maximum weed suppression was likely to result from leguminous mixtures with contrasting canopy characteristics.

A fairly new approach of conservation biological control that could maximize ecosystem services is the habitat management strategy which aims to provide additional plant species that favour the presence of natural enemies to insect pests by providing shelter, food (pollen, nectar), and alternative hosts/preys (Landis *et al*., 2000; Fiedler *et al*., 2008). The four most commonly used species in such habitat management studies are *Phacelia tanacetifolia* Benth. (phacelia), *Fagopyrum esculentum* Moench (buckwheat), *Lobularia maritima* (L.) Desv. (alyssum), and *Coriandrum sativum* L. (coriander) (Fiedler *et al*., 2008).

A potential component of disease management in apple orchards within a sustainable ecosystem is the use of ground cover plants. Brown and Glenn (1999) used flowering ground cover plants [dill, *Anethum graveolens* L., buckwheat, *Fagopyrum esculentum* Moench; dwarf sorghum, *Sorghum bicolor* (L.) Moench; and rape, *Brassica napus* L.] beneath the trees as disease management tools in apple orchards in eastern West Virginia. They compared a conventional orchard that received five applications of an organo-phosphate with a ground cover orchard which received only one broad-spectrum insecticide (phosmet) plus *Bacillus thuringiensis*. Diseases were managed in the same way in both orchards. In terms of diseases, the conventionally managed orchard had more fireblight and apple scab damage than the ground cover one, but less rot diseases. The greater incidence of fire blight in the conventional orchards was explained by the fact that fireblight is more severe in vigorous trees. The lower incidence of apple scab in ground cover orchards was attributed to the plant stubble left over. More rapid leaf decomposition occurs over winter in the ground cover stubble, and reduces movement of ascospores because of decreased wind speeds within a few cm of the orchard floor. Finally, rot diseases were more abundant in ground cover orchards because ground cover plants create a humid microclimate (Rosenberg, 1974) which is favourable for the disease cycle. In this study, even though ground cover reduced insecticide use, it was not an acceptable alternative tool to conventional disease management because it resulted in yield reduction, probably due to competition by the ground cover vegetation for water and nutrients. However, if ground cover plants are managed in a better way so as to avoid competition with apple trees, their use seems a promising tool for the control of diseases in a sustainable apple orchard because they can provide favourable microhabitat for natural enemies (Rosenberg, 1974) and also food in the form of nectar and pollen.

Leius (1967) evaluated 15 apple orchards with poor, intermediate and rich flowering understory plants in Ontario, Canada. The flowering plants included in the rich orchard were strawberry (*Fragaria* sp.), buttercup (*Ranunculus* sp.), hawkweed (*Hieracium* sp.), clover (*Trifolium* sp.), dandelion (*Taraxacum* sp.), violet (*Viola* sp.), fleabane (*Erigeron* sp.), white mustard (*Sinapis alba*), willow (*Salix* sp.), wild cherries and plums (*Prunus* spp.), wild carrot (*Daucus carota*), wild parsnip (*Pastinaca sativa*), blue-eyed grasses (*Sisyrinchium* spp.), white daisy (*Chrysanthemum* sp.), milkweed (*Asclepias syriaca*), sweetclover (*Melilotus* sp.), alfalfa (*Medicago sativa*), goldenrod (*Solidago* sp.) and aster (*Aster* sp.). It was found that the mean parasitism of codling moth larvae was five times higher in the species- rich orchards compared to the species-intermediate and species-poor orchards.

A study was conducted in a cider apple orchard in Spain to examine the effects of ground cover management on ground beetles (Coleoptera: Carabidae) which may help the biological control of pests (Miñarro and Dapena, 2003). There are several earlier studies in which carabids predate on codling moth larvae in apple orchards; although Riddick and Mills (1994) concluded that *Pterostichus* species were the most effective predators of codling moth. The results of the study by Miñarro and Dapena (2003) were that eight species of carabids were collected with *Steropus gallega* Fairmaire (65.8%), *Pseudophonus rufipes* (De Geer) (18.2%) and *Poecilus cupreus* L.(14.6%) being the main three, representing more than 98% of the total. The greatest number of carabids were found in the tilled (rotovated) plots (24.3%) followed by the herbicide-treated plots (21.4%), while plastic mulch had the lowest numbers (5.6%). Furthermore, the tilled and herbicide-treated plots had the highest activity density as well as the highest richness, diversity and evenness indices.

A two-year study was conducted in apple orchards in northern California to assess the effect of cover crops: field bean (*Vicia faba*), lana vetch (*Vicia dasycarpa*), farmers’ rye, tetraploid rye, ladino clover (a form of *Trifolium repens*), salina strawberry clover, Mt. Barker subclover (*Trifolium subterraneum*), and a natural weed complex on arthropod populations (Altieri and Schmidt, 1986b). The components of the natural weed complex were curly dock (*Rumex crispus*), bristly ox-tongue (*Picris echioides*), curled dock (*Epilobium adenocaulon*), water smartweed (*Polygonum coccineum*)[1], groundsel (*Senecio vulgaris*), smooth sow thistle (*Sonchus oleraceus*), and wild mustard (*Brassica* spp.). The results showed lower densities of aphids, codling moth and leafhoppers in the cover-cropped orchards compared to those orchards lacking vegetation cover (disked orchard). More fruit were damaged by codling moth in the disked orchard compared to the cover-cropped one in both years of the study (78% versus 68% in 1982; 38.8% versus 4.2% in 1983). The lower rates of insect pests in the cover-cropped orchards were mainly correlated with the greater variety and number of natural enemies (predators and parasitoids) present in the cover-cropped orchards, which were attracted by the alternate prey (aphids, leafhoppers) which the cover crops harbour. More ants and spiders were found in the cover-cropped orchard compared to the disked in both years. The fact, however, that many natural enemies are harboured on the cover crop does not necessarily mean that high numbers of these will be found on the trees as well. The authors therefore suggest investigating how to better manage the cover crops so as to optimize the biological control of pests, by testing, for example, whether mowing of the cover crops encourages natural enemies to migrate to the trees (Altieri and Schmidt, 1986b).

In Germany, a study was carried out to test whether it is possible to enhance the biological control of aphids in an apple orchard using flowering strips (Vogt and Weigel, 1999). The orchard was divided into two parts; one half was sown with a grass mixture as green cover and the other half with an alternation of grass with a flowering plant mix in consecutive alleys. The plant species included in the flowering mixture were: *Sinapis arvensis*, *Fagopyrum esculentum*, *Medicago lupulina*, *Lotus corniculatus*, *Trifolium incarnatum*, *Vicia faba*, *Anthemis tinctoria*, *Centaurea cyanus*, *Centaurea jacea*, *Chrysanthemum leucanthemum*, *Matricaria chamomilla*, *Melandrium album*, *Knautia arvensis*, *Reseda lutea*, *Foeniculum vulgare*, *Daucus carota*, and *Carum carvi*. Of the plant species included in the flowering mixture *S. arvensis*, *A. tinctoria*, *C. jacea*, and *D. carota* provided good ground cover (between 30 and 100%). The aphids found in the orchard were the rosy apple aphid (*Dysaphis plantaginea* Pass.) and the green apple aphid (*Aphis pomi* De Geer) with the rosy apple aphid dominating. In terms of beneficials, spiders (Araneae) were the dominant species (41.6-61.8% depending on the year). The study showed

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[1] This plant is known as amphibious bistort in the UK, formerly *Polygonum amphibia* i.e. synonomous with *Polygonum coccineum*.

that the use of flowering strips failed to control the rosy apple aphid because there was no overlap between the development of the aphid population, the flowering period of the plant species in the flowering mixture and the appearance of the beneficial animal species. The use of flowering strips proved to be beneficial for the control of *A. pomi* because the beneficial fauna was enhanced. It was therefore suggested to use flowering strips in combination with a neem product (NeemAzal-T/S) which according to Schmutterer (1995) is very efficient for the control of *D. plantaginea* and not harmful for many beneficial species (cited in Vogt and Weigel, 1999). This product, however, is not currently approved for use in the UK and a specific application would need to be made for such approval.

In an apple orchard in Switzerland the effects of weed strips on aphids and aphidophagous predators were investigated (Wyss, 1995). At the time of flowering of the weeds higher numbers of aphidophagous predators were observed in the weed strip area compared to the control with spiders, Coccinellidae, predacious Heteroptera and Chrysopidae being found in greater abundance. As a result of this, less aphids and aphid infestation were found in the weed strip area. According to Vogt and Weigel (1999) possible explanations for the different results of these two studies with regard to *D. plantaginea* infestations might be the different apple varieties used, the different size of the orchard and the different way of managing the flowering strips. In Switzerland the effect of artificial weed strips on the diversity and abundance of beneficial arthropods has been evaluated.

An experiment was carried out at Horticulture Research International East Malling in 1994 and 1995 to investigate the ability of flowering plants to enhance numbers of beneficial arthropods in UK apple and pear orchards and contribute to biological control of pests in the UK orchards (Fitzgerald and Solomon, 2004). Of the 14 flowering plants used, only five, cornflower (*Centaurea cyanus* L.), corn marigold (*Chrysanthemum segetum* L.), corn chamomile (*Anthemis arvensis* L.), phacelia (*Phacelia tanacetifolia*) and buckwheat (*Fagopyrum esculentum* Moench) showed consistent flowering throughout the sampling period. Three of the most attractive plant species corn chamomile, cornflower and corn marigold were used in mixtures to assess the effect of flowering plants on pest populations. Different plant species attracted different groups of beneficials. Corn chamomile and cornflower attracted the greatest numbers of anthocorids (Hemiptera: Heteroptera), while spiders were most abundant on corn chamomile and corn marigold, coccinellids (ladybirds, Coleoptera: Coccinellidae) on cornflower and Hymenoptera on corn chamomile and corn marigold. In terms of chrysopids (lacewings, Neuroptera: Chrysopidae) there was no difference between the different flower species. Few beneficials were found on phacelia and the most attractive species was cornflower. The study showed that several flowering plant species (cornflower, corn chamomile, corn marigold) have the potential to attract beneficial insects which can negatively affect fruit pests indicating therefore their potential to reduce the populations of some pests in UK orchards. The use of flowering plants in this experiment had no adverse effect on yield and both number and weight of class 1 and class 2 fruit were unaffected, in contrast to Brown and Glenn (1999) who reported reduced apple yield when the trees were undersown with flowering plants, probably due to competition for water and nutrients. Therefore it was suggested that the use of flowering plants in the tree rows may be commercially acceptable only in areas with relatively high rainfall levels. Other alternative approaches include the use of plants in the headlands and margins of the orchard, or in the grass alleys (e.g. Wyss, 1995) or as strips along the boundaries between the grass alley and the herbicide strip (e.g. Brown and Glenn, 1999).

Bostanian *et al*. (2004) tested the ability of four flowering plants (*Tanacetum vulgare*, *Chrysanthemum maximum*, *Aster tongolensis* and *Achillea millefolium*) to attract beneficial arthropods (predacious and parasitoid) in an apple orchard in Quebec. The quality of fruit at harvest was assessed as a pest management index and it was found that in the fifth year of the study the percentage of undamaged fruit was 90.8% compared to 67.5% in the control, which is an amount of damage close to commercially acceptable levels. The authors emphasized, however, that in the commercial situation it would take several years for the beneficial arthropods to become sufficiently established to be an effective bio-control agent.

Another study was conducted in apple orchards in Victoria, Australia to evaluate the effect of cover crops on natural enemies and pests. The cover crops were selected so as to benefit natural enemies but not pests. The cover crops bullwort/fennel (*Amni majus*/*Foeniculum vulgare*), chicory/yarrow (*Cichorium intybus*/*Achillea millefolium*), white mustard (*Sinapis alba*), buckwheat (*Fagopyrum esculentum*) and fenugreek (*Trigonella foenum-graecum*) were compared with volunteer grasses and a commercial grass mix. Unlike other studies, there was no increase in the activity of natural enemies due to cover crops; this may be explained by the fact that the beneficial effects of the cover crops do not apply where annual rainfall (<800 mm) is limited (Bone *et al*., 2009). This is thought to be because in low rainfall areas the main crop would compete with the cover crops for moisture, restricting the successful reseeding and establishment of the cover crops (Bone *et al*., 2009).

A study was conducted in an apple orchard in South America (northern Patagonia region of Argentina) to evaluate the effect of cover crops on the presence of arthropods (Fernández *et al*., 2008). The cover crops studied [tall fescue (*Festuca arundinacea*) + lucerne (*Medicago sativa*), strawberry clover (*Trifolium fragiferum*), common vetch (*Vicia sativa*), and natural vegetation of grasses and legumes as the control treatment] were applied between the tree rows, while a 1 m wide herbicide (glyphosate) strip was maintained within the tree rows. Generally, the cover-cropped soil had increased number and diversity of arthropod species compared to the exposed soil. The arthropod community collected included 119,117 individuals, 52.9% of which were phytophagous species and 41.9% beneficial species. The main beneficial species collected were coleopterans (Carabidae, Staphylinidae, and Coccinellidae), parasitoid hymenopterans, spiders, predator bugs (Nabidae, Geocoridae, and Anthocoridae) and lacewings. The fescue + alfalfa and strawberry clover had the highest diversity with 59.9 and 56.2% of beneficial species respectively (Fernández *et al*., 2008).

Bostanian *et al*. (2005) have suggested a grower-friendly method to control phytophagous mites in apple orchards in Quebec, Canada. Usually, the phytophagous mites are managed with naturally occurring beneficials (predacious mites). However, in the case where these are not present or they are not in sufficient number for adequate control, the authors suggest transfer of predacious mites from a donor orchard to the release orchard in winter and summer. This was achieved by means of pruned wood, which should have 20-25 leaves and at least one predator per leaf. Moreover, the release orchard should be lightly infested by phytophagous mites, which would be there to provide food for the predators to become established. The study showed that the two main families of predacious beneficials found on pruned wood were Phytoseiidae (*Typhlodromus caudiglans*) and Stigmaeidae (*Agistemus fleschneri*).

Brown and Mathews (2005) suggested a novel orchard design for eastern North America, which is both environmentally and economically sustainable. Compost mulch, companion plants, interplanting and the use of disease resistant cultivars are all elements of the sustainable system they propose. The authors suggest redesigning the orchard according to Figure 4. The orchard consists of a standard width grass alley every other tree row for the machinery to perform the horticultural activities required. The narrower alleys with companion flowering plants will increase the diversity of the insect natural enemies. The trees within the row are widely spaced for easy spraying, but the overall tree density remains the same because every other alley is narrower, which allows more rows per hectare. Several peach trees are interplanted within each row of apple trees to serve as a nectar source. Brown and Schmitt (2001) interplanted peach trees bearing extrafloral nectaries in an apple orchard and found that the diversity of arthropod predators and parasitoids on apple trees was increased. The authors suggest 20-50 peach trees per hectare. The much warmer winters and cooler summers, however, would probably make peach not a good choice for the UK but other earlier-flowering nectar rich tree species (possibly nectarines or apricots) could be interplanted with apple trees- in the way peach has been used in the US- to increase the abundance of beneficial insects, provided they did not harbour fireblight. Some of the principles behind this approach should be explored in the context of UK cider orcharding.

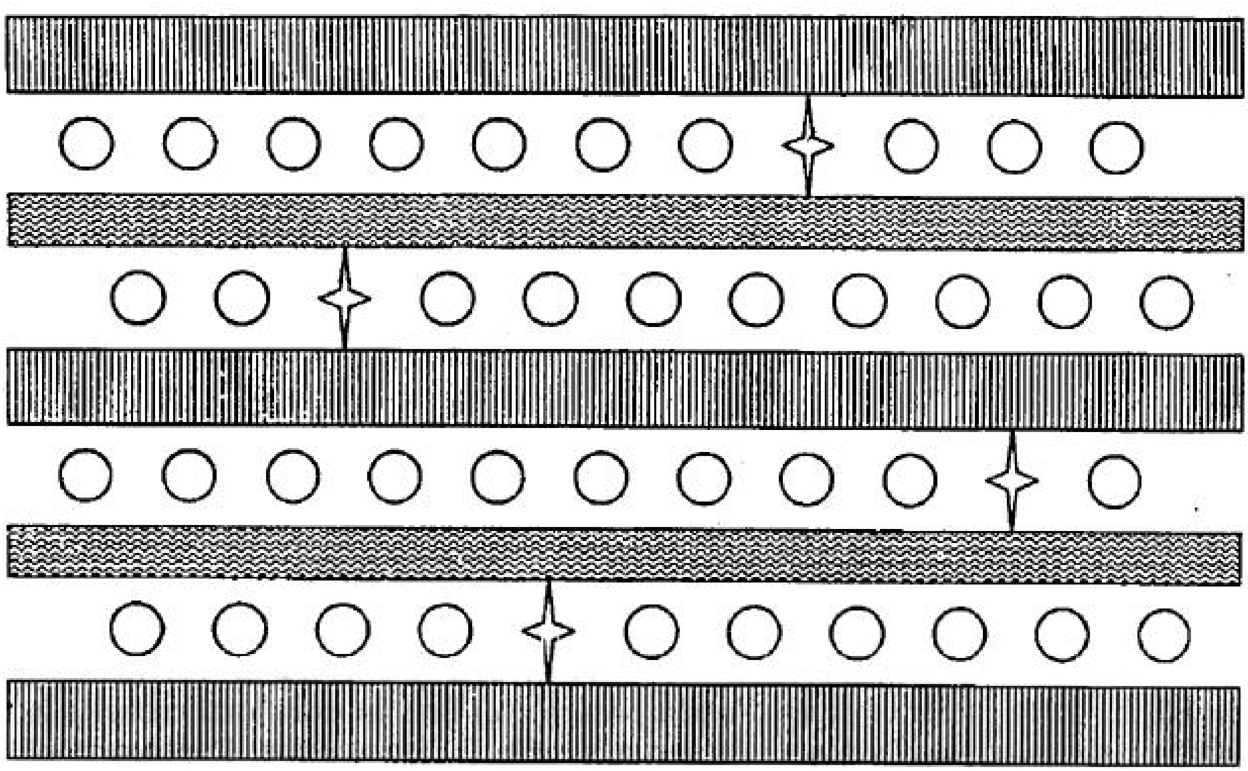


Fig. 4: A novel orchard system (where: vertical hatching=grass alleys; wavy line hatching=strips of companion flowering plants; stars=peach trees, and circles=apple trees) (from Brown and Mathews, 2005)

Two commercial flower mixtures (Tübingen Mixture from Germany and Ascot Linde SN from the Netherlands, containing 12 and five plant species respectively) were tested in Hertfordshire as food sources for attracting beneficial insects in the UK (Carreck and Williams, 1997). The observations showed that 14 species of Hymenoptera, 14 species of syrphid Diptera, and six species of Lepidoptera visited the flower mixtures. In both of the mixtures, even though they contained many plant species, *Phacelia tanacetifolia* was the most successful species in terms of establishment, flowering and attractiveness to beneficial insects, while the contribution by the other species of the mixtures was small. These two flower mixtures, however, proved unsuitable for the UK conditions because they flowered during the period when other nectar sources like *Tilia* spp., *Brassica napus* and *Vicia faba* were available and therefore the insects attracted by the mixtures were few. The authors suggest that a more suitable mixture for the UK conditions should have more late flowering and fewer early flowering plant species (Carreck and Williams, 1997). This is an area for future research (see Part 3).

Conclusions

One way to maximize ecosystem services is through habitat management, a practice which favours the presence of natural enemies and therefore the biological control of pests assuming that damaging pesticides (to the beneficials) are not going to be used. Phacelia tanacetifolia *Benth. (phacelia),* Fagopyrum esculentum *Moench (buckwheat),* Lobularia maritima *(L.) Desv. (alyssum), and* Coriandrum sativum *L. (coriander) are the most commonly used species in habitat management studies. A number of studies have been conducted to evaluate the effect of cover crops, artificial weed strips, flowering plants and other ground cover management practices (herbicides, mulches, tillage) on the biological control of pests through enhancing natural enemy population and performance. The majority of the studies resulted in lower rates of damage by insect pests, but the same results may not apply under commercial conditions in UK cider apple orchards and therefore further more detailed research is required.*

1.3 Orchard design and agroforestry

1.3.1 Orchard systems for cider apples

Functionally, the majority of the traditional cider orchards in Europe formed silvopastoral systems (combining tree fruit production and pasture) until around 1950. These systems consisted of large, long-lived, low-density plantings where management was not a major concern (Merwin *et al*., 2008), with limited or no pesticide inputs since the appearance of the fruit was not as important as in dessert apples (Copas, 2001). The traditional cider orchard consisted of widely spaced rows (about 7.6-9 m apart) of 6-12 m tall trees with a broad canopy (7.6 m) and high main branches starting 1.8-2.1 m from the ground. They were designed to be suitable for fruit growing, but at the same time to provide easy penetration of light for adequate pasture growth so as to be suitable for livestock grazing (Lombard and Williams, 1974; Quinion, 1979; NACM, 1980; Merwin, 1999). In such systems, budding of scions was done high above the ground using seedlings or vigorous rootstocks (Merwin *et al*., 2008). These traditional standard trees were difficult to harvest and occupied considerable space. As a result, during the 1970s these orchards were generally replaced with higher density plantings (400-600 trees per hectare compared to 100-150 for a standard orchard) of trees 1.8-4.6 m high with a canopy spread of 6 m. In France, in the 1950s, the government subsidized growers to change their traditional pasture cider orchards and by the 1990s most had moved to modern systems with intensive plantings of productive varieties using MM106 rootstocks which were managed in a similar way to dessert apple orchards (Merwin *et al*., 2008). Similarly, in the UK during the 1970s growers replaced their traditional cider orchards with the modern system determined by the development of a large-scale cider industry (Copas, 2001). This use of semi-vigorous rootstocks (primarily MM106) made grazing impractical (NACM, 1980; Hardy, 1982; Rendell, 1984; Hogue and Neilsen, 1987), and gave earlier and heavier production than the traditional standard pastoral system. Modern intensive cider apple trees come into full cropping after 8 years whereas standard trees do so after 15 years, and also give yields of about 20-25 tonnes/hectare compared to 10-12 tonnes/hectare for standard trees (NACM, 1980; Legg, 1984). The optimum production figure for modern intensive cider apples is now considered to be 50-55 tonnes/hectare (Richard Heathcote, pers. comm.). In Spain, in contrast, growers have maintained the traditional system (Merwin *et al*., 2008).

1.3.2 Sward composition and design

Permanent orchard floor vegetation is the most commonly used orchard floor management system and consists of a permanent cover of grasses or other plants (Hogue and Neilsen, 1987). A permanent grass sward can be a very effective means of protecting soil conditions by maintaining or increasing soil organic matter (Greenham, 1952). This system protects the orchard soil from water erosion and compaction caused by mechanical equipment, in contrast to mechanical cultivation; it can be used on its own where vegetation is mowed, or in combination with mulch, within the tree row or herbicide strip (Hogue and Neilsen, 1987). Permanent sward management either involves mowing weeds that grow in the orchard, a method which prevents vigorous weeds from growing and allows other useful grasses and plants to take over, or the sowing of a mixture of grasses, or mixed grasses with legumes, for weed suppression.

We will now discuss historical trials (because the work that has been done to assess this in the UK largely stopped in the 1980s), recognizing that new, improved grass cultivars may offer different opportunities which were not available at the time this research was carried out. A large scale trial established at East Malling in 1940 (Rogers *et al*., 1948; Greenham, 1952) compared 30-year old Worcester Pearmain trees in grass and clover swards with plots receiving summer cultivation. Three complex grass and clover mixtures were sown whilst other treatments involved different frequencies of mowing and five fertilizer treatments on the sward plots. All three grass mixtures checked the growth and cropping of trees initially, but after a few seasons the trees fully recovered in those plots which were either frequently mowed to reduce competition from grass, or included the addition of nitrogen fertilizer on mixtures which did not contain the vigorous grass cocksfoot (*Dactylis glomerata*). Mowing six or seven times per year with a gang-mower gave good results in comparison with three cuts per year with a hay mower which was harmful to the trees. After 13 years Greenham (1952) reported that the best grass treatments maintained tree growth at the same level as summer cultivation, but considerably reduced the proportion of pre-harvest drop so that the amount of picked fruit was markedly increased and improvements in fruit colour were found (a feature often reported under grass swards). Greenham (1952) concluded that, because of the initial check to tree growth, grassing down was only recommended after five years, before which summer cultivation was recommended with the application of organic manures, mulches or annual cover crops to provide a supply of organic matter.

Chippingdale (1957) also reported a negative effect of initial sowing with perennial ryegrass (*Lolium perenne*) and that cocksfoot may be a better species to sow than ryegrass since it was easier to mow and less liable to develop seed (ryegrass was difficult to mow in wet weather and had a tendency to seed heavily in summer, although since this time there has been much improvement in ryegrass varieties). Subterranean clover (*Trifolium subterraneum*) was unsuited to gang-mowing and became a 'tumbledown' (poor condition) sward. Where nitrogen levels were high, annual meadow grass (*P. annua*) became the dominant grass of 'tumbledown' sward and was typical of intensively managed sward. Rough stalked meadow grass (*P. trivialis*) and *Agrostis* spp. later accompanied *P. annua* when mowing was less frequent. White clover (*Trifolium repens*) sown alone gave dense swards, but was rapidly invaded by *Poa*, which was further increased by application of N fertilizer (the longest period for white clover to persist as the dominant species was four years). S.50 Timothy (*Phleum pratense*) gave very satisfactory results as it was an easy grass to mow and provided a dense sward. Red fescue (*Festuca rubra*) had no obvious advantage and was sometimes difficult to mow and developed a surface mat which could cause run-off of rain on sloping ground.

Greenham and White (1966) described the results of a 12-year trial of six contrasting swards (S.23 perennial ryegrass, S.50 Timothy and chewings fescue (*Festuca rubra* sbsp. *commutata*), each with white clover, white clover alone, subterranean clover and allowing a natural sward to develop in which annual meadow grass was initially dominant) performed at East Malling on bush trees of the desert apple variety Laxton's Fortune on M11 planted in 1945-46 at 6 m x 5 m five years after planting. Swards were mown closely and frequently except for the perennial ryegrass. The cropping of the trees over the 12 years was inversely related to the vigour of the swards which was highest under the perennial ryegrass, lowest under the natural sward and intermediate under the timothy swards. These differences in vigour determined the severity of competition for both water and for nitrogen. The chewing fescue did not become established and was taken over by annual meadowgrass and perennial ryegrass which also occurred in the white clover plots. Subterranean clover also failed to establish. There was no evidence of any beneficial effect of sowing clover in any of the mixtures. Greenham and White (1968) also described a 12-year trial of three contrasting soil management systems (frequently mown S.23 perennial grassland sward, a permanent overall straw mulch and summer cultivation) on the same Laxton Superb trees. Tree growth was greatest under the straw mulch but this was not reflected in yields until a lighter pruning regime was adopted towards the end of the study. Trees under clean cultivation grew and cropped well during the first half of the trial but later yields were lower because of cultivation injury to the trees. Grassing down initially reduced growth and yield due to competition for the first half of the trial but gave satisfactory growth and yield in the second half of the trial after receiving a higher rate of nitrogen application. Green and Stockham (1966) reported four years' observations on Cox's Orange Pippin following grassing down in 1956. A distinct check to growth and cropping was observed with perennial ryegrass and clover but less under S.50 Timothy and clover, whilst the best results were obtained where clover alone was sown.

Work on grass swards continued in the 1960's at Long Ashton Research Station with the introduction of chemicals to provide control of weeds without the need for cultivation. Stott (1965) described a trial using a growth retardant (Maleic Hydrazide, MH) to restrict growth of grass and 2,4-D to control dicotyledonous weeds, since this could enable trees to be established on arable ground and with direct planting into sward. Grass was favoured over cultivation as grass restricted nitrogen available to the tree which was considered advantageous since it prevented imbalances between vegetative and reproductive growth. Also spraying, harvesting and other aspects of management were more easily carried out on grass. However, regular cutting of grass was costly and chemical methods of sward control were considered to be economically important. Application of MH and 2, 4-D resulted in little growth of the sward until eight weeks after spraying. However, by mid-August, one third of sprayed areas were covered in dead vegetation with bare patches. Most weeds were retarded by MH except for field speedwell which increased as grasses died. No significant differences in cropping were detected. Later work (Stinchcombe and Dumas-Copas, 1981) suggested improved results with swards treated with paclobutrazol. Although white clover (*Trifolium repens*) was a promising ground cover species for orchards it was rapidly invaded by more dominant grass species.

Stott *et al*. (1975) described trials on Cox and Golden Delicious in which paraquat and carbetamide applied as a double application gave an almost pure clover sward. Propyzamide increased clover from 6% to 68% in an unsprayed area. Stott *et al*. (1975, 1976, 1977) also describe herbicide trials on Cox and Golden Delicious in which the highest yields and most vigorous trees were those on plots kept weed free with simazine and paraquat. However, as noted in earlier studies, grass cover gave better coloured fruit with improved fruit nutrient content (Ca, P & K). Un-mowed white clover gave very promising results during the first four years, but in the very dry weather of 1976, clover competed very strongly with trees for water which resulted in lower yields and smaller apples. During this year soil moisture deficits were greater under the clover sward compared with weed-free plots, whilst grassed alleyways maintained by mowing or applying MH/2,4-D were intermediate. In the following year there was no significant difference in soil moisture deficit until August when the white clover was again significantly drier than weed free areas. The report also noted that strawberry clover (*Trifolium fragiferum*) removed less water than white clover and so competed less strongly for water. Strawberry clover also withstood the 1976 drought better. Although clover plots yielded least in 1976, they yielded the most in 1977.

Monoculture trials have also been carried out in work mainly outside the UK (see Table 2), but there was a difficulty in keeping the monocultures free from weeds and dense enough, so as to provide adequate soil coverage (Lipecki and Berbeć, 1997). Orchardists show a preference towards natural swards because they are cheaper than seed mixtures (Lipecki and Berbeć, 1997). Other trials have been conducted to test the use of permanent cover crops only in the tree rows with other soil management methods between the rows (Lipecki and Berbeć, 1997). Another system is the so-called 'Swiss Sandwich' which retains weeds within the apple tree row to reduce water loss, but is shallow tilled either side, adjacent to the grass alley to reduce competition (Stefanelli *et al*., 2009). The most commonly used species for the permanent orchard floor vegetation system (full width or restricted to interrows) are given in Table 2.

Table 2: Species that have been used in experiments for permanent sward (compiled from Lipecki and Berbeć, 1997)

Method	Species
Naturally occurring sward	*Lolium perenne* L.
	Poa annua L.
	Elytrigia repens L.
	Taraxacum officinale Web.
	Stellaria media Vill.
	Trifolium repens L.
Sowing seeds of mixed grasses or mixed grasses with legumes	*Lolium perenne* L. (dwarf cvs)
	Festuca rubra L.
	Festuca ovina L.
	Poa compressa L.
	Poa pratensis L.
Monocultures	*Festuca arundinacea* Schreb
	Lolium perenne L.
	Festuca ovina L.
	Muhlenbergia schreberi L.
	Trifolium repens L.
Permanent cover crops	*Potentilla reptans* L.
	Festuca ovina L.
	Glechoma hederacea L.
	Trifolium repens L.

Several legume species (*Trifolium repens* cvs. White clovers Huia, S184 and Kent; red clover, *T. pratense*; crimson clover, *T. incarnatum*; strawberry clover, *T. fragiferum*, trefoil *Medicago lupulina*; British Seed Houses A17 legume mixture) and a low maintenance grass, lissete dwarf ryegrass were used in a trial on weed free soil strips of young Ashton Bitter trees (Copas, 1994/2010). All three white clover cultivars had a rapid germination and good establishment, forming a dense mat but they caused depletion of soil moisture and nitrate. Red clover and trefoil were less competitive but inadequate in terms of weed suppression. BSH A17 legume mixture and strawberry clover had a slightly slower establishment but provided good weed suppression. So, these studies suggested that legumes make good green mulch for weed suppression but can seriously inhibit growth of young trees especially in dry summers, because they compete for water (Copas, 1994/2010).

In trials carried out at Long Ashton Research Station, a mixture of chewings fescue (*Festuca rubra commutata*) and browntop bent (*Agrostis castellana* 'Highland') was compared with dwarf turf-type ryegrasses for cider orchard alleyway swards. The fescue/bent mixture has been the standard recommendation for cider orchards for many years because it provides a rapid establishment of a compact, weed-resistant, stable, shade-tolerant sward. Dwarf turf-type ryegrasses, however, could be an alternative sward which is inexpensive and easy to establish and is less competitive with the trees for water and nutrients. Suitable dwarf ryegrass cultivars require only four mowings per season, while the fescue/bent mixture requires six or more (Copas, 1989).

A trial was carried out to assess the best available grass mixtures for orchard alleyways and for grassing down under established tree rows. BSH A22 (60% Lorina dwarf ryegrass, 35% Logro slender red fescue, 5% Highland browntop) and Barenbrug rye/fescue mixtures (50% Barcredo dwarf ryegrass, 30% Barcrown slender red fescue, 20% Bargreen chewings fescue) gave an excellent low maintenance sward with steady regrowth after mowing. PRO 120 (60% Lisabelle dwarf ryegrass, 35% Liprosa slender red fescue, and 5% Highland browntop) had a quicker regrowth and contained a more vigorous ryegrass which required more frequent mowing. BSH A6 (40% Boreal red fescue, 30% Wilma chewings fescue, 20% Julia smooth meadowgrass, 10% Highland browntop) formed an excellent sward. BSH A7 (50% Hermes dwarf ryegrass, 20% Julia smooth meadowgrass, 10% Frida chewings fescue, 10% Wilma chewings fescue, 10% Highland browntop) and Barenbrug (20% Barlow dwarf ryegrass, 20% Barcredo dwarf ryegrass, 30% Barcrown slender red fescue) also formed good swards but contained vigorous ryegrass which competed with the trees (Copas, 1994).

More detailed information on orchard design and agroforestry can be found in the 'Replacement of cider orchard herbicide strips with a mat-forming perennial vegetation cover' review (Vysini *et al*., 2011).

1.3.3 Intercropping

A common practice for dessert apple trees in the traditional orchards with widely spaced rows was to intercrop the alleyways in the early years (Williams, 1996). Intercropping is the practice of growing two or more food crops at the same time on the same area of land (Willey, 1979). Even though intercropping was a practice undertaken in dessert apples it can also take place in cider orchards (Williams, 1996). The benefits of intercropping include an additional income for the grower from the intercrop, especially in the early years when the apple trees have not come into full cropping, and weed suppression. However, the intercrop alone is not capable of providing complete weed suppression and therefore additional control of weeds is required. This is achieved by hand weeding in developing countries, since it is quite difficult to find selective herbicides that could be applied to both crops because the main crop and the intercrop usually belong to different families (Hartwig and Ammon, 2002). Intercropping has also been used as a form of biological control for several insect pests. In a Chinese study, five aromatic plants (*Centaurea cyanus*, *Saturela hortensis*, *Nepeta cataria*, *Ageratum houstonianum*, and *Ocmium basilicum*) were tested as intercrops in a pear orchard. All aromatic plants reduced the pest population especially the Homoptera (*Psylla chinensis*, *Pseudococcus comstocki* Kuwana, and aphids) when compared with the natural grass plots, with *C. cyanus*, *S. hortensis*, and *A. houstonianum* having the most noticeable effect. This significant reduction in pest population was correlated to an increase in the number of natural enemies to pests or the repelling of pests. However, the requirement of the intercrop is to attract only natural enemies and from this point of view the aromatic plants are suitable candidates because their volatile oils attract many predators and parasitoids (Song *et al*., 2010) and also the nutrients of the plants provide a source of food to them. Finally, they have the advantage that they tolerate a degree of shade (Song *et al*., 2010).

In an Indian study carried out in mandarin orchards with seven different intercrops (wheat, maize, cotton, marigold, chickpea, soybean, okra) it was found that the trees intercropped with legumes (soybean and chickpea) had higher fruit yield (72.2 kg/tree) compared to the non-leguminous intercrops and monocropped trees (68.5 kg/tree), plus an extra yield obtained from the intercrop which ranged from 0.10 t/ha (cotton) to 2.80 t/ha (marigold) (Srivastava *et al*., 2007). Even though a variety of intercrops have been used in bush orchards, it proved that most of these had serious problems such as restricting the access of mechanical equipment required for spraying or harvesting practices (Umpelby and Copas, 2002). Williams (1996) questions whether anything will be gained from intercropping in cases where the alley width is less than 5.5 m. In more generous alleyways several crops could be used such as cereals, strawberries, silage grass, root crops, and early potatoes (Williams, 1996). Bulmers' contracted growers have tried corn, linseed, flax, and silage as intercrops without any success (Durrant and Durrant, 2009). Durrant and Durrant (2009) mention blackcurrant, strawberries, asparagus, potatoes, maize, and daffodils among the most common intercrops for orchards.

1.3.4 Grazing

Traditionally cider apple trees were widely planted as standards and the orchard had a dual function of livestock and cider production. A variety of livestock (chickens, pigs, cows, turkeys, and sheep) can graze apple orchards and this approach is still in use. However, whenever grazing takes place livestock should be removed at least 56 days before harvest the fruit to avoid the danger of faecal contamination, which is a requirement of the cider manufacturers. Another disadvantage of having livestock is the fact that they add an extra cost to the apple grower because they are labour-intensive (Durrant and Durrant, 2009).

A study was conducted in Canadian apple orchards to determine the effectiveness of grazing hogs on the control of weeds and grasses that grow in the orchard and also for the control of plant diseases by removing windfalls. Two different hog densities were tested (46.45 m^2/pig and 24.40 m^2/pig) and both were equally effective. Leaves, fruit, soil and manure were analyzed to determine the risks of contamination by total coliforms and *Escherichia coli*. Leaves and fruit of the grazed plots were free of *E. coli* and very few *E. coli* were found in soil samples. The practice of grazing hogs was also very successful in removing windfalls from the orchard floor. Less that 4% of windfalls remained in the grazed plots compared to the control. The results of the study show that despite the concern about *E. coli* contamination related to grazing livestock in an orchard, there is a potential for such grazing, provided it is accompanied by good management (i.e. avoid grazing for two months before harvest) (Nunn *et al.*, 2007).

Conclusions

Permanent orchard floor vegetation is the most commonly used control method preventing soil erosion and compaction. Several grass/grass-legume mixtures have been tested over the years including ryegrass, white clover, S.50 Timothy and red fescue with good results. Dessert apple trees were traditionally intercropped with benefits for the grower such as additional income, weed suppression, and biological control of insect pests (e.g. the use of aromatic plants reduced the pest population in a pear orchard). Several crops have been tested as intercrops without great success. Grazing was a practice common in traditional cider orchards, but it needs to be accompanied by good management.

1.4 Waste reduction

Waste is a problem in orchards and where it is generated it should be dealt with in an environmentally acceptable way. Good environmental practice towards more sustainable orcharding involves both waste minimisation and effective management of waste. Major waste products of an orchard are: prunings and trash, empty chemical containers, containing pesticides and fertilisers, and apple pomace.

1.4.1 Prunings and trash

A large amount of waste biomass is produced in apple orchards as a result of cultural practices such as pruning and thinning. The current situation with prunings and trash is that they are often shredded on-site and left to mulch into the sward, or they are composted; in either case they are not classified as waste. Prunings and trash may also be burnt, in which case they are classified as waste. Rupasinghe *et al*. (2007), in a chemical composition analysis showed that apple orchard waste is a valuable bio-resource. Spring pruned twigs, summer pruned leaves and stems and hand-thinned immature fruit were analysed for phenolic compounds and compared with mature fruit. Summer pruned leaves had the highest total phenolic content (810.2 mg/100 dry weight) followed by spring pruned stems (320.2-245.0 mg/100 dry weight), and immature fruit (324.4 mg/100 dry weight), while mature fruit had the lowest total phenolic content (42.7 mg/100 dry weight). As the authors suggested, this indicates that a potential use of orchard waste (prunings) could be the extraction of polyphenolics which are of interest because of their antioxidant properties in relation to human health and they suggested that an application of these compounds could be their use in the food industry as natural antioxidants which might replace synthetic ones, and add an alternative source of income for apple growers (Rupasinghe *et al*., 2007)

Wood from pruned apple orchards could be used as a source of renewable energy. Several advantages of wood, which make it one of the most valuable biofuels, are its high calorific value (13.6-14.6 MJ/kg, similar to that of brown coal), the emission of less dangerous fumes, and the small amount of ash after burning. This ash can also be used as a natural fertilizer. The large amount of wood generated annually in orchards and fruit plantations after pruning could therefore be used for energy generation. More data are required in terms of the amount of wood generated from pruned apple orchards in order for this alternative way of utilising it to be assessed. A study was conducted in Poland for this purpose, and concluded that the amount of wood from pruned apple orchards depended on the age of trees and growth vigour of individual cultivars with the highest amount of cut wood obtained from the oldest trees (Rabcewicz *et al*., 2010). Another study was carried out in the Netherlands in order to evaluate organic waste from agriculture and the agrofood industry that could be used as a renewable source for energy production; pruning wood from fruit trees was one of the most important among the agricultural waste streams. The available pruning wood from Dutch fruit trees amounted to 550 kt/year, from which 4400TJ/year of energy could be produced if the whole waste stream was used for energy production (Hiddink, 1997).

1.4.2 Biochar

Biochar is 'the porous carbonaceous solid produced by thermochemical conversion of organic materials in an oxygen depleted atmosphere which has physiochemical properties suitable for the safe and long-term storage of carbon in the environment and, potentially, soil improvement' (Shackley *et al*., 2010). Typically, during pyrolysis approximately 50% of the carbon contained in biomass is retained within biochar which is significantly greater than the carbon recovered from composting equivalent biomass (Laird, 2008). Moreover, biochar has a very slow rate of decomposition so that, if applied to land, it remains in the soil for very long periods (more than 100 years), making it an attractive option for long-term carbon sequestration in the soil (Atkinson *et al*., 2010). The use of biochar in agriculture is not new and has its origin in pre-Columbian times, when continuous slow burning of vegetation was used to create nutrient rich *terra preta* soil in the Amazon basin which was used for crop production by the Amazon tribes

(Navia and Crowley, 2010). Once applied to soils, biochar can increase soil fertility/nutrient availability by increasing the cation exchange capacity. Biochar application can also improve soil water holding capacity and reduce environmental pollution (e.g. fertilizer, pesticide and heavy metal contamination) (Atkinson *et al*., 2010; Navia and Crowley, 2010). Global production of biochar has been estimated to be between 0.05 and 0.3 Gt (10^9) C yr^{-1} (Atkinson *et al*., 2010). Lehmann *et al*. (2006) estimate that the carbon stored in soil through biochar programmes could be 9.5 billion tonnes by 2100. There is evidence that the use of biochar for the sequestration of atmospheric carbon to the soil could be a potentially efficient climate change mitigation route (Atkinson *et al*., 2010). Development of biochar production facilities for cider apple orchards is an area which is worth pursuing (see Part 3).

1.4.3 Agrochemical containers

Another major waste form is empty agrochemical containers. An increase in the consumption of plastics in agricultural and horticultural applications has been observed between 1991 and 1995 (Cooper, 1998). Sacks (fertilisers, feedstuffs etc.) have increased from 13,500 to 15,000, while packs for agrochemicals increased from 10,000 to 10,950 (Cooper, 1998). Agrochemical packaging accounts for about 5% (over 4000 tonnes) of the packaging delivered to farms every year which end up as waste (Goldsworthy and Carter, 1998). Even though it represents a small percentage of the UK's total packaging waste (10 million tonnes), it is the nature of the contents that raises concerns in relation to disposal (Goldsworthy and Carter, 1998).

Disposing and then burning waste at a licensed waste disposal site (bonfires) has raised concerns about nuisance and dark smoke. A small survey (Goldsworthy and Carter, 1998) carried out in the UK with 15 farmers/farm managers found that 14 of them were burning the pesticide containers on farm and only one was using a waste disposal contractor, a finding consistent with previous research which showed that the majority of farmers (over 70-80%) were burning containers, 20-30% were burying them, and only 0-10% had the containers collected by a waste disposal contractor (Goldsworthy and Carter 1998). A similar investigation was carried out on 85 farms in Italy (55 cereal farms and 30 orchard farms). In both types of farms, the empty pesticide containers were mainly burned, while only 3% of the orchard farmers had their containers collected by a specialised firm (Balsari and Airoldi, 1998).

Even though burying plastic agrochemical containers involves limited risk of environmental pollution because the empty containers have been previously cleaned, it is not a good way to dispose of them as they are made of a robust material which degrades very slowly and because they are buried at a depth where there is no microbial activity (Goldsworthy and Carter, 1998). Return, re-use and recycling of empty containers are better options in relation to waste reduction (Gilbert, 1998). However, the problem is that the empty containers may contain chemicals, including residual pesticides (Cooper, 1998). Rinsed containers, on the contrary, can be collected for re-use and refilled with the same product they initially contained (Gilbert, 1998). In some cases there has been a shift towards supply of agrochemicals in the form of solids, powders and granules, which means that the containers could be more easily emptied (Cooper, 1998). Another approach is to keep re-usable/refillable containers in a closed circuit between the supplier and the user (Cooper, 1998). Small-volume refillable pesticide packaging has been commercially used since 1995. In Canada the use of such containers has proved to have potential in reducing the amount of plastic packaging used. In 1986, Ciba (now part of BASF) introduced 400 litre refillable containers with pumps for use in the United States. However, they proved to be unsuitable and unreliable for UK farmers because of their large size (Mills-Thomas *et al*., 1998).

Whatever the method of disposal, thorough cleaning of the empty containers is required (Smith, 1998). Based on this, a survey was carried out by the British Agrochemicals Association to evaluate the degree to which farmers were cleaning their empty pesticide containers. The survey was posted to 783 farms, 263 of which responded (33.6%). The majority of farms over 150 hectares in size had rinsing devices fitted to their sprayers; of those which did not, over 80% were rinsing their containers three times (Goldsworthy and Carter, 1998). In Australia, over 90% of farmers rinsed their containers at least once and most of them were using landfills to dispose of containers (50%), or were storing them on farm (38%) (McGuffog, 1998). In another survey in Canada, 69% of the farmers interviewed said that they rinsed containers because they wanted to use the entire product they had purchased; the reason for not rinsing was lack of time (Cook, 1998).

Empty containers if not returned and re-used, burned, or buried, could be recycled either as raw material for manufacturing other plastic items, or burnt as fuel for energy production (Gilbert, 1998). In Germany, empty, properly rinsed agrochemical containers are taken back and recycled by manufacturers and wholesalers, a practice which became nationwide for the first time in 1996 (Neck, 1998). A similar program has operated in Canada since 1989, in which empty pesticide containers are collected and recycled. Two-thirds of the plastic from the shredded containers collected in 1996 were used to manufacture fence posts for agricultural use and the rest was used as a fuel source in industrial plants (Cook, 1998).

1.4.4 Apple pomace

Apple pomace is the main by-product of the juice and cider industry worldwide and represents 25-35% of the dry mass of apple (Gullón *et al*., 2007). It consists of peel, seeds, core, stems and exhausted soft tissue (Diñeiro García *et al*., 2009). In 1999 more than 107 million kg of apples were processed for ciders and juices in the United States, of which 27 million kg became apple pomace (Roberts *et al*., 2004); overall, 1300 million kg of apple pomace is produced in the USA annually (Carson *et al*., 1994), with annual disposal fees being estimated at $10 million (Worrall and Yang, 1992). In Asturias, northern Spain, one of the largest cider producing areas worldwide (AICV, 2000), more than 20,000 tonnes of apple pomace is produced; this is mainly used as cattle feed (Diñeiro García *et al*., 2009). Pectin manufacture is the only other use performed at an industrial level (Gullón *et al*., 2007). 800,000 tonnes of apple pomace are produced in Brazil annually and this is mainly used as animal feed (Vendruscolo *et al*., 2008). In India, annual production of apple pomace is about 1 million tonnes of which only about 10,000 tonnes is being utilised, the rest is generally thrown away, and creates environmental pollution (Shalini and Gupta, 2010). Thus in general apple pomace is generated in high volumes, and its disposal is a major issue for the apple processing industry (Cohn and Cohn, 1996). Its direct disposal to soil or landfill may no longer be an acceptable practice due to environmental concerns, so the potential uses of apple pomace need to be explored (Carson *et al*., 1994). Several uses of apple pomace have been reported, and these will now be discussed.

Apple pomace has been widely utilised as cattle feed (Shalini and Gupta, 2010). Because of its high moisture content (80-85%) it spoils quickly (Roberts *et al*., 2004) so it is often dried prior to use as feed (Cohn and Cohn, 1996). Edwards and Parker (1995) in New Zealand found that it was a useful supplementary feed for lactating dairy cows on pasture-based diets during autumn. Inclusion of apple pomace in the feed of cows resulted in increased daily milk yield (20-30%), as well as milk fat, milk solids and protein. Narang *et al*. (1991) evaluated apple pomace as a feed for cross-bred calves and concluded that it could be safely incorporated at a rate of 12% in the ration of calves without any negative effects. However, in general apple pomace is considered a poor animal feed supplement because it is very low in protein and vitamin content, high in sugar, and is only available seasonally (Hang *et al*., 1981). It can also be utilized to feed sheep (Alibes *et al*., 1984).

Press aids are used by juice processors when extracting the juice from the raw fruit in order to optimize the amount of juice obtained (Roberts *et al*., 2004). According to van Deelen and Steinbuch (1983) conventional press aids have the disadvantage that they convey undesirable flavours to the juice (cited in Roberts *et al*., 2004). Roberts *et al*. (2004) therefore evaluated the effectiveness of dried apple pomace as a press aid to improve the quality of strawberry, raspberry and blueberry juices. Apple pomace was made to a press aid and compared with conventional rice hulls and paper press aids. In terms of juice yields, no significant differences were found between juice pressed using the conventional press aid, to juice pressed using dried apple pomace, for both strawberry and blueberry juice. However, the use of apple pomace press aid significantly reduced raspberry juice yield. In terms of colour, the strawberry juice pressed with apple pomace was significantly redder than the strawberry juice pressed with rice hulls, while there was no significant difference in the colour of raspberry and blueberry juices. In terms of flavour, those juices pressed with apple pomace were preferred over those pressed with conventional press aids. In terms of the aroma, strawberry juice pressed with rice hulls had more negative off-flavours. The same was the case with raspberry juice pressed with rice hulls, where 10 out of 11 aroma compounds detected were rice aroma compounds and only one was reported exclusively as a raspberry compound. Similarly, in the blueberry juice pressed with apple pomace 10 of the 11 aroma compounds were blueberry aroma compounds, while when blueberry juice was pressed with paper, only three compounds were detected as blueberry aroma compounds. All three berry juices had higher soluble solids (^{o}Brix) and sugar-acid ratio with apple pomace press aid compared to conventional press aids. Therefore, the results of the study indicate that dried apple pomace is promising as an alternative press aid for berry juices.

Apple pomace was assessed as a substrate for the production of shiitake [*Lentinula edodes* (Berk.) Pegler] and oyster mushroom [*Pleurotus ostreatus* (Jacq. ex Fr.) Kummer and *P. sajor-caju* (Fr.) Sing.] in New York. Both types of mushroom produced higher fresh weights when grown on a 50:50 (on a dry-weight basis) mixture of apple pomace and sawdust than on 100% apple pomace or 100% sawdust suggesting a potential as a substrate amendment (Worrall and Yang, 1992). Apple pomace is rich in nitrogen and readily usable carbohydrates (Hang, 1987) that add to the nutritive value of sawdust, but it was a poor substrate on its own (Worrall and Yang, 1992). In India *Pleurotus membranaceus* Massee and *P. euosmus* (Berk. apud Hussey) Sacc. have been found on rotting apple pomace in nature; both of these are reported to be edible mushrooms (Upadhyay and Sohi, 1988).

A study was conducted by Hang *et al*. (1981) to determine the possibility of producing ethyl alcohol from apple pomace via solid-state fermentation. 43g of ethyl alcohol could by produced per kg of apple pomace. Alcohols produced included methyl, ethyl, propyl, butyl and amyl, with ethyl being produced at the highest levels. The production of alcohol from apple pomace could be useful considering the increasing energy costs.

Several studies report the use of apple pomace as a supplement in container growing media. According to Van de Kamp (1986) composted pomace was of acceptable quality for plant growth especially for seedlings. South Shelburne Cider Company composted pomace and applied it in young orchards where it improved tree growth (Van de Kamp, 1986). Parks (1979) on the contrary, reported that vegetable crops had reduced yield and vigour when grown in fields treated with apple pomace. Chong (1992) evaluated the use of apple pomace as an organic supplement for container culture of four ornamental nursery species in Canada: silverleaf dogwood (*Cornus alba* L. 'Argenteo-marginata'), euonymus [*Euonymus fortunei* (Turcz.) Hand.-Mazz. 'Emerald Gaiety'], Andorra juniper (*Juniperus horizontalis* Moench 'Plumosa Compacta') and Emerald cedar (*Thuja occidentalis* L. 'Smaragd'). These grew well and there was no significant difference in shoot dry weight or in leaf nutrient composition associated with growing medium. Andorra juniper grown in media containing 75% or 90% apple pomace actually had higher shoot dry weight, compared to medium with 25%, 50% or no pomace. However, the growing medium should contain no more than 50% pomace because 75% or more pomace causes serious shrinkage of it (>20%).

Apple pomace is also considered to be a good potential source of polyphenols. In recent years there has been an increasing interest in natural food polyphenols as an alternative to synthetic substances which are used in the food, pharmaceutical and cosmetic industries (Djilas *et al*., 2009). In a study by Lu and Foo (1997) to identify and qualify the major polyphenols in apple pomace it was found that the total level of the polyphenols in the pomace was about 7.24 g kg^{-1} dry matter, the majority of which consisted of quercetin glycosides (4.46 g kg^{-1} dry matter), indicating apple pomace has potential as a source of polyphenols. Other major compounds isolated and identified included epicatechin, caffeic acid, phloridzin. The juice obtained from a conventional apple juice production process was poor in phenolics and contained only 3-10% of the antioxidant activity of the fruit used for its production (Van der Sluis *et al*., 2002) so the fact that most of the polyphenols remained in the apple pomace, together with the naturally high content of polyphenols made it promising to explore apple pomace as a food additive, and for the recovery of these compounds (Djilas *et al*., 2009). In an Irish study apple pomace was also found to be a good source of polyphenols and antioxidants (Wijngaard *et al*., 2009). The overall conclusion is that apple pomace, which is in abundance, could be used to develop ingredients rich in polyphenols as healthy food additives. Natural extracts high in antioxidant activity can also be used as food additives for colour and flavour preservation, and therefore shelf life improvement (Moure *et al*., 2001).

The use of apple pomace as a raw material for manufacturing other food-related products (lactic acid, fibre-rich concentrates, and pectin) is also attractive. Gullón *et al*. (2007) used samples from the cider industry to measure the potential of such pomace for the production of lactic acid. The comparative advantages of this material as a raw material for lactic acid manufacture are its high content of polysaccharides and metal ions (Mn, Mg, Fe and others), and the presence of mono-, di- and oligosaccharides, citric acid and malic acid. Apple pomace is a natural source of fibres (cellulose, hemicelluloses, pectin, β-glucans, gums and lignin) and diets rich in fibres play an important role in the prevention, reduction and treatment of several diseases (Vendruscolo *et al*., 2008). In another study by Figuerola *et al*. (2005), fibre concentrates from apple pomace were evaluated in order to be included in the enrichment of foods. Fibre concentrates from apple pomace had interesting characteristics such as high dietary fibre content, which could permit the use of pomace in the development of new natural ingredients for the food industry (Figuerola *et al*., 2005). Carson *et al*. (1994) used unrefined, dried apple pomace as an ingredient in pie filling and oatmeal cookies, while Patt *et al*. (1984) used apple pomace powder to enrich bread with fibre (cited in Shalini and Gupta, 2010). Masoodi *et al*. (2002) concluded that apple pomace can be incorporated into cakes without having an undesirable effect on their physical properties. It has also been used as a source of dietary fibre in wheat bread in India, where it was concluded that breads containing up to 5% pomace were acceptable and did not change the quality of the bread (Masoodi and Chauhan, 1998).

Another use of apple pomace is in the production of pectin. According to Lopez *et al*. (1990), apple waste produced during juice extraction, and the skin of citrus fruits, were the two main sources of commercial pectin. Apple pomace pectin is characterised by superior gelling properties compared to citrus pectins (Schieber *et al*., 2001; Djilas *et al*., 2009). However, the brown hue of apple pectins caused by oxidation is a limitation for their use in light-colour foods.

A NACM trial was carried out in 1989 to test cider apple pomace as weed suppressant mulch. After the juice extraction, the residual pectin was removed from the apple pomace and the pectin extracted fruit (PEF) was used as a mulch in a cider orchard planted with Ashton Bitter. The results of the trial showed that the PEF mulch was successful in suppressing annual weed growth and also it encouraged the tree growth, however, it needed replacing every year. It was also cheap and easy to apply (Copas, 1997).

Despite the fact that apple pomace could be utilized in many different ways, the ideal use in terms of economic potential has not been found yet (Kennedy *et al*., 1999); the production of pectin, which has long been extracted from apple pomace (Sharma *et al*., 1985), being the most reasonable way of utilizing apple pomace both from an economical and ecological perspective. However, the fact that apple pomace is produced in large quantities during apple processing makes the production of a single product not economically feasible and production of all possible products needs exploration (Kaushal *et al*., 2002).

Conclusions

Minimisation and effective management of waste is important for sustainable orcharding. Major waste products are prunings and trash, and apple pomace. Pruning waste has been found to be rich in polyphenols; a potential use for the extracted polyphenolics has been proposed to be in the food industry, as natural antioxidants. Another alternative use of pruning waste is as a renewable source for energy production or as a soil amendment, as biochar. Empty agrochemical containers are a waste product the concerns for which are mainly related to the hazardous nature of their contents. Burning and burying are methods of disposal, but re-use and *recycling are better options. Many uses have been suggested for apple pomace such as cattle feed, press aid, a substrate amendment, a supplement in container growing media, production of alcohol, a source of polyphenols and pectin; however, the ideal use in terms of economic potential has not yet been found. The development of biochar facilities for apple prunings and trash should be a priority (see Parts 2 & 3).*

1.5 Varieties for climate change and optimized fruit quality

1.5.1 Varieties for mitigating the effects of climate change

Evidence indicates that global climate change is taking place and will have significant effects on biological processes over the coming decades. Although there is controversy over the reasons behind global warming, the adverse effects are clear and of great concern all over the world (Hedhly *et al*., 2008). Increases in average temperatures and atmospheric CO_2, as well as alteration of the rainfall regimes are amongst the expected climatic changes (IPCC, 2007). It is projected that the current 360 μmol mol^{-1} CO_2 concentration could have increased to be between 560 and 970 μmol mol^{-1} by the mid to late 21^{st} century. As a result of the increased CO_2 concentration mean air temperature is projected to increase by up to 5.8^{o}C (Houghton *et al*., 2001).

The exact pattern of temperature change will vary according to geographic location. In a study by Sunley *et al*. (2006) six chill unit models were tested in the UK's main soft fruit producing locations. The locations for which data were obtained include East Malling Research, Kent; the Scottish Crop Research Institute, Invergowrie, Tayside; Pershore College, West Midlands and Morley, St. Botolph, Norfolk. The chill models tested include the '< 7.2^{o}C' (h) model; the '<7.2^{o}C' (d) model; the '0-7.2^{o}C' (h) model, the '0-7.2^{o}C' (d) model, the 'Utah' model (developed for peach) and the 'Lantin' model (developed for blackcurrant) (h and d refer to number of hours and days respectively). All the models apart from the 'Utah' showed that all the regions studied (Tayside, East Anglia, the West Midlands and the South-East) have had significant reductions in winter chill since the 1960s with the largest changes in the South-East and the smallest in the north of the UK (Tayside). However, the different chill models gave different outcomes in terms of chill accumulation in the different geographic locations of the UK and the selection of the best and most appropriate model for predicting the effects of climate change depended on the crop. In the case of the soft fruit crops (blackcurrant and raspberry) studied here, for example, the '<7.2^{o}C' and 'Lantin' models were the most suitable.

In California two different chilling models (Chilling Hours; Dynamic Model) were used in order to investigate future changes in winter chill (Luedeling *et al*., 2009). The models showed that climatic conditions will become less suitable for the cultivation of tree crops and in many cases production will not be possible. It is anticipated that by the end of the 21st century areas with winter chill suitable for growing walnuts, pistachios, peaches, apricots and plums (>700 chilling hours) will no longer exist in California. For crops such as apples, cherries and pears with a chilling requirement (CR) of >1000 hours, very few locations that fulfil these CR were found to exist currently, and the model predicted that nearly none will be available by mid-century (Luedeling *et al*., 2009).

Kronenberg (1979, 1985 and 1989) used modelling methods to define a line across Europe which indicated the regions where sufficient winter chilling was currently available (below 100m above sea level). They predicted flowering dates of two varieties (Belle de Boskoop and Golden Delicious), and estimated the northern limits for production of four varieties (White Transparent, Cox's Orange Pippin, Golden Delicious and Granny Smith) of apple in Europe. The studies used either generally applicable figures or limited sets of varieties for estimating chilling requirement across varieties but whilst they demonstrate well the application of models to assess or predict environmental suitability to apple growing they were not carried out with a focus on either cider varieties or a changing climate.

The physiological basis for the chilling requirement is as follows (see Battey, 2000 for further details). The buds of deciduous fruit trees are dormant during the autumn and winter in temperate climates. This dormancy period consists of an endodormancy phase followed by an ecodormancy phase (Lang *et al*., 1987). Chilling temperatures are perceived during autumn and winter, and the cumulative effect of chilling is the main factor related to the breaking of endodormancy. Once the buds are released from endodormancy, the length of the ecodormancy phase is related to environmental conditions (primarily temperature) that restrict the active growth of the buds. In this way the combined effects of winter and spring temperatures determine the time of bud opening and spring flowering (Legave *et al*., 2008).

In mild climates, the time of bud break is closely related to the winter chilling requirement of the tree. With global warming, winter temperatures are unlikely to be low enough for sufficient time to fulfil the CR of apples in traditional apple growing regions and this will be a problem. For this reason, low-CR apple cultivars will be more appropriate. It should be noted, however, that if bud break occurs early there could be an increased risk of frost damage. Oppenheimer and Slor (1968) developed a breeding project to produce apples with low CR and high fruit quality suitable for warm climates. Their hybrids were expected to be suitable for a climate with 200-300 hours below 7^{o}C during the winter. For this purpose, the breeding program used as parents local varieties with low CR and very low fruit quality, the most important being one unnamed type from Damascus, and the Palestinian cultivar 'Biari'. The parents were then crossed with established varieties (e.g. Astrachan, Delicious, Jonathan and Lodi). Three varieties with low CR and improved quality were introduced from this program: 'Anna', 'Ein Shemer' and 'Schlor'. In another, Brazilian, breeding program, 'Mollie's Delicious' has been used with success as a low chilling source. Other low chill varieties include 'Adina', 'EarliDel', 'Goldina', 'Princessa', 'SummerDel', and 'Primicia' which is also scab-resistant (Janick *et al*., 1996).

The dessert cultivars with low CR which were initially made commercially available, such as 'Anna' had poor fruit quality (Hauagge and Cummins, 1991). It is very important therefore to develop low-chilling cultivars of higher quality for climate change mitigation. 'IPR Julieta' is a new productive cultivar, with good fruit quality and good performace in locations that accumulate 100-500 chill units (Hauagge, 2010).The development of such cultivars requires the hybridization of high quality (high CR) parents with parents having low CR (and maybe low quality fruit). Knowledge of the heritability of CR is important for the development of successful breeding programmes (Hauagge and Cummins, 1991). The study by Hauagge and Cummins (1991) showed that rapid genetic progress towards the aim of developing high-quality apple cultivars with low CR could be achieved by crossing 'Anna' with cultivars that have high quality and high CR. Other low CR cultivars that could be used include 'Dorsett Golden' and 'Ein Shemer'. By crossing these low CR cultivars with higher quality, high CR cultivars 'Liberty' and 'Jonafree', which are also resistant to diseases, low CR, high quality disease-resistant apples could potentially be produced. Research in South Africa is developing knowledge in this area with a view to breeding low CR varieties and 'Anna' has been used recently in the identification of a QTL for vegetative bud break (see Section 1.5.3).

According to De Salvador and Di Tommaso (2003) other options with the potential to cope with a reduction in winter chill include the use of dormancy-breaking chemicals that can compensate for insufficient chilling in many crops (e.g. cherries) (cited in Luedeling *et al*., 2009). However, there are several limitations related to this option; one is that such chemicals are successful only during the later stages of the dormancy period (Erez, 1995). It has been found that they are not effective if applied early, while late applications might cause bud damage and yield reductions. Their successful application therefore requires thorough knowledge of the tree's dormancy period and accurate winter chill models (Luedeling *et al*., 2009). Furthermore, environmental concerns restrict the use of such chemicals. Breeding would therefore appear to be the preferred option for cider apples; the potential value of establishing a breeding programme is emphasized in Part 3 of this report.

Recently published research assessing the chilling requirement of apples for production with a view to the changing climate has been somewhat reactive and has therefore focussed on the areas which are most immediately affected. Studies have focussed on Brazil, India, and South Africa (for examples see Petri and Leite; Mankotia *et al*. and, Labuschagne all 2004). To support either the selection or breeding of suitable varieties for UK cider production it would be necessary to apply similar studies to establish baseline data specific to cider varieties and the cider producing areas of the UK as this represents a clear gap in current knowledge.

One of the most readily observable effects of climate change is on plant phenology (Schwartz, 2003). The timing of flowering is a key developmental stage for plants which has been found to be altered by climate warming (Tooke and Battey, 2010). For example, one study in south-central England found that the average first flowering date of 385 British plant species occurred 4.5 days earlier in the 1990s compared to the previous four decades (Fitter and Fitter, 2002). Alteration of flowering timing in fruit trees due to global surface temperature increases is very important because an earlier flowering may place the trees in danger of damage by late frosts. If frost overlaps with the flowering period it can severely harm the flowers resulting in crop failure. Such late frost damage with severe impact on apple yields happened in Europe in 1981 (Chmielewski *et al*., 2004).

The timing of flowering also affects the plants' chances of pollination, especially if the pollinator is seasonal and the timing of flower production does not overlap with the timing of pollinator's flight activity. Therefore, any changes in flowering time will have an impact on pollination (Fitter and Fitter, 2002). Flower pollination is a key step in the sexual reproduction of angiosperm species most of which rely on insects or other animals rather than wind for transfer of pollen. Pollination is a mutually beneficial ecological interaction since insects transfer the pollen and they benefit by obtaining nectar and pollen. Humanity also benefits directly through the yield of the crops (Memmott *et al*., 2007). These authors predicted that phenological alterations due to global warming will reduce floral resources of all pollinator species and increase the percentage of pollinator activity period which does not overlap with any food plant. The disruption of plant-pollinator interactions due to global warming is most important for pollinators which are more specialized with small diet ranges; most pollinators, however, rely on more than one plant species (Memmott *et al*., 2007).

Pollination may also be particularly vulnerable to the effects of global warming through the effect that high temperatures have been shown to have on pollen performance during the stage of pollen development (Hedhly *et al*., 2008). Hedhly *et al*. (2003) studied the effect of temperature on stigmatic receptivity in sweet cherry (*Prunus avium* L.) both in the laboratory and in the field. Stigmatic receptivity was reduced with high temperature and the stigma lost the capacity to support pollen penetration. Pollen germination and pollen adhesion were also reduced. Similar results have been found in a wide range of crops (Barnabás *et al*., 2008), including other fruit crops (Karapatzak *et al.*, under review).

In view of the concern about the adverse effects of climate change on pollination with subsequent effects on crop yields, the availability of apple varieties which set fruit without pollination could be relevant. 'Spencer Seedless' and 'Wellington Bloomless' are two apple varieties (*Malus pumila*) with apetalous flowers. Their flowers do not attract bees but they can produce fruit without pollination (Tobutt, 1994). Tobutt (1994) crossed these two apetalous apples with 'Wijcik', a bud mutant of McIntosh which has a columnar growth habit (see Section 1.5.3 for Marker Assisted Breeding (MAB) relating to the columnar trait). These crosses gave apetalous columnar apples which have the advantage that they are suitable for high density orchards and can crop without pollination. They are therefore independent of bees, pollinator varieties and warm weather at flowering time. There are several other papers that make reference to apetalous apples. Stout (1929) reported that breeding programmes at Geneva, New York were using apetalous apples; Dennis (1970) mentioned 19697 and 19726, two seedless apetalous New York selections and others in Germany or Russia [Ewert (1929); Kobel (1931); Chernenko (1953); Cuprinjuk (1969); Eliseev (1979); Pomonarenko (1980)] (cited in Tobutt, 1994).

Cropping of such parthenocarpic apples, however, is a problem that several authors emphasize. According to Dennis (1970) from five apetalous varieties or selections, only 'Spencer Seedless' showed a consistent heavy crop, while Pomonarenko (1980) described some apetalous types which never produced fruit and others that produced fruit only if they were pollinated artificially (cited in Tobutt, 1994). Another problem with these varieties is their poor fruit quality. It is therefore doubtful whether any of the apetalous columnar selections could be of direct commercial use; however, several selections from these could be useful as parents, for example Tobutt (1994) described selections from SA633, SA736, SA737, with better quality; SA633, with easy rooting and resistance to mildew; SA712, with resistance to scab. The mutation associated with parthenocarpic fruit development and the apetalous character in apple has been shown to cause loss of function of a gene homologous to *PISTILLATA*, a key homeotic regulator in *Arabidopsis* flowers (Yao *et al*., 2001).

The majority of apple cultivars are self-incompatible and require cross-pollination to produce fruit. Cross-pollination requires pollen from another apple cultivar and therefore it is common practice for a commercial orchard to introduce other cultivars as pollinizers. These cultivars should be compatible with and flower at the same time with the main crop and they should not be biennial so as to provide pollen continuously. Growers usually plant pollinizers as every third tree in every third row. Heavily pruned crab apple trees can be planted as pollinizers so as not to occupy a lot of space (Dennis, 2003). Tobutt (1994) suggests that columnar apple trees would be suitable for intensive tree plantations as pollinizers because their compact growth habit means that they would occupy little space when planted among the trees of the main crop.

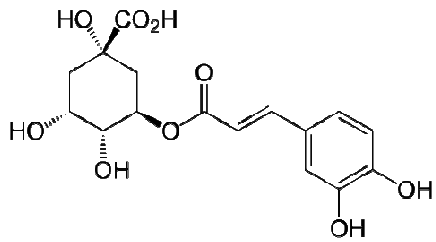
Many cider apple cultivars are self-fertile (Michelin, Dabinett, Sweet Coppin, Stoke Red, Dove, Yarlington Mill, Reinette Obry, Kingston Black, Tardive Forestier, Frederick) (Williams, 1954) and may therefore be potentially important as parents in breeding programmes (see Part 3). However, self-pollination can be variable from year to year, for reasons that are not understood. The pollination requirements of cider apple varieties therefore need to be studied carefully and systematically over several years (see Williams, 1954). Authors, therefore, tend to recommend that pollinizers are always needed, even with varieties which are considered self-fertile. Data on the self-compatibility loci for the cider accessions in the National Fruit Collection generated by researchers at East Malling (Defra project GC0140) are included in Appendix 2 and available within the NFC database.

Finally, one additional element, key to the ability of apple varieties to mitigate the effects of climate change may be the development of rootstocks able to cope with altered availability of water. Current work at East Malling is focussing on the development of genomic tools for the pre-selection of water-use efficiency in rootstocks (Defra project WU0115). Whilst the development of markers and knowledge on water-use efficiency of rootstocks will be directly applicable to rootstocks for both dessert and cider varieties, it is expected that, as with most current research, the major efforts will be weighted toward dessert varieties and it would be worthwhile looking to incorporate these findings into the development of rootstocks particularly suited to cider apple production.

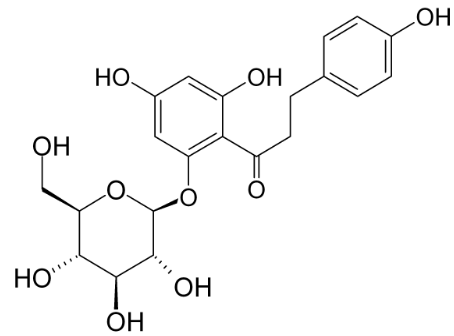
1.5.2 Varieties for optimized fruit quality

Apples produced commercially are classified as dessert (e.g. Cox's Orange Pippin), culinary (e.g. Bramley's Seedling) and cider (e.g. Dabinett). All three classes of apples can, however, be used for cider making. In the West Country for example cider has traditionally been made from true 'cider' apple varieties, while in Sussex and the Eastern Counties dessert and culinary apples are often used. Cider is usually made from a blend of varieties with sweet, sharp and bitter characters in order to achieve the appropriate balance of sugar, acid and tannin. Bramley's Seedling for example, which is a culinary apple, is frequently blended with cider apples to give the acidity required (Williams, 1996). Around 100 UK cider cultivars are still cultivated, although only about 15 are currently in modern intensive orchards (Lea, 2004). These true cider varieties typically have high sugar content (up to 15%), a range of acidities (0.1-1%), a fibrous structure that facilitates pressing and gives more juice, a high tannin content (ten times higher than in dessert apples), which contributes to mouthfeel, a pleasant apple taste and aroma, and they can be stored for several weeks without adverse effects on texture when their starch converts into sugar (Williams, 1996; Bamforth, 2005). The traditional classification for English cider apples, as developed by the Long Ashton Research Station, identifies four groups based on the acid and tannin content of the juice: bittersharp with high tannin content (>0.2%) and high acid content (>0.45%); bittersweet with high tannin content (>0.2%) and low acid content (<0.45%); sharp with low tannin content (<0.2%) and high acid content (>0.45%); and sweet with low tannin content (<0.2%) and low acid content (<0.45%) (Williams, 1996). 'Tannin' is a term which was initially used for substances that tanned protein (Beech and Garr, 1977). For a long time it was employed imprecisely to refer to the total polyphenol content of ciders (Lea, 1990a). However, it has been found that only procyanidins bind with protein (Beech and Garr, 1977) and therefore they are the only true tannins found in apples, even though all the other phenolics of apples are usually mentioned as 'tannins' (Lea, 1990b).

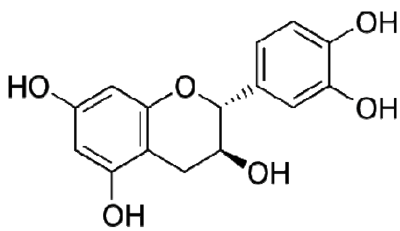
According to Lea (1974) the phenolic compounds present in cider are classified into the following groups: phenolic acids, which are usually found as esters of quinic acid with chlorogenic (5-caffeoylquinic) acid being the most important; phloretin derivatives (dihydrochalcones) with phloridzin the most important; simple catechins with (-)-epicatechin the most important; and condensed procyanidins with procyanidin B2 the most important (Beech and Carr, 1977). The chemical structure of these compounds is given in Figure 5. However, it should be mentioned that the phenolics present in the cider-apple juice differ from those found in the whole apple fruit, because some compounds such as flavonol glycosides and anthocyanins are mainly found in the peel of the apple (Sanoner *et al*., 1999) where they remain during the process of juice extraction (Beech and Carr, 1977). Phenolics are important for the appearance, taste and quality of cider (Marks *et al*., 2007a) and they are also associated with the balance between astringency and bitterness, which is responsible for the overall 'mouthfeel' of ciders (Lea and Drilleau, 2003). Astringency is a drying, puckering sensation in the mouth in which the whole tongue is affected, while bitterness is mostly perceived at the sides and back of the tongue. Astringency and bitterness are due to polymeric and oligomeric procyanidins respectively (Lea and Arnold, 1978). Other reasons for the importance of phenolic compounds in cider include their contribution to its colour and aroma (Sanoner *et al*., 1999).



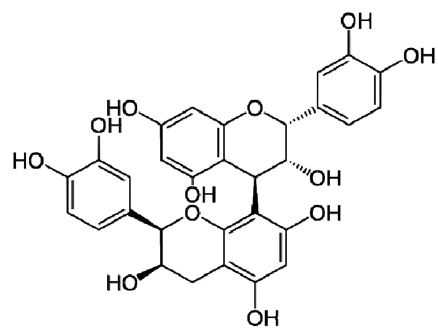
Chlorogenic acid



Phloridzin



(-)-Epicatechin



Procyanidin B2

Fig. 5: Chemical structure of main classes of apple polyphenols (Lea, 1990a)

Marks *et al*. (2007a) analysed the phenolics of 19 cider apples (Ashton Bitter, Brown Snout, Browns Apple, Broxwood Foxwhelp, Bulmers Norman, Chisel Jersey, Dabinett, Ellis Bitter, Harry Masters Jersey, Major, Medaille d'Or, Michelin, Reine des Hâtives, Somerset Redstreak, Sweet Coppin, Taylors Sweet, Tremletts Bitter, Vilberie, Yarlington Mill) and one dessert apple variety (Golden Delicious) and found that the cider apple varieties were richer in phenolics than the dessert apple and also that the peel had more phenolics than the flesh. The phenolic content of the peel was 546-6306 mg kg^{-1} fresh weight and that of the flesh 230-4920 mg kg^{-1} fresh weight. 15 compounds from five different phenolic groups were detected with 5-O-caffeoylquinic acid, procyanidin B2 and (-)-epicatechin predominating in the flesh and (-)-epicatechin and quercetin glucosides in the peel. Yarlington Mill and Medaille d'Or had the highest phenolic content in both the peel and the flesh and the sweeter varieties generally had lower phenolics than the bitter. The authors suggested that obtaining information about the phenolic content of cider apples has increasing contemporary relevance, because by choosing apples with higher phenolics, cider makers could look to increase its contribution to the intake of phenolics from the diet. According to Epps (2005), Dabinett and Michelin are the two major varieties used by HP Bulmers (up to 56% of the apples used) (cited in Marks *et al.*, 2007a), which could be replaced by other varieties which are richer in phenolics, such as Yarlington Mill and Medaille d'Or.

Sanoner *et al*. (1999) studied the polyphenol composition of the fresh cortex of 14 French apple varieties (12 cider and two juice varieties), one English cider variety (Dabinett) and one dessert apple (Golden Delicious). Procyanidins were the main class of polyphenols in all 16 varieties analysed. The polyphenol concentration was 1-7 g/kg depending on the variety, with cider varieties showing a higher polyphenol concentration compared to the dessert apple and bitter varieties having the greatest concentration. Golden Delicious had the lowest total polyphenol content (1.04 g/kg), while the French variety Jeanne Renard had the highest (6.99 g/kg). The English cider variety Dabinett was twelfth with total polyphenol content of 3.41 g/kg fresh weight.

Fatty acids are very important because they contribute to the sensory quality of foods. They contribute to flavour as precursors of volatile compounds and they can also be converted into flavour and fragrance products. Fatty acids such as linoleic and oleic acid inhibit foam formation (MacLeod, 1977). Therefore, controlling fatty acids is important because the ability of cider to form foam is an important characteristic in terms of how attractive the product is to the consumer. In cider, high foam stability is connected to a decrease in sensory assessment. The fatty acid composition of 30 monovarietal apple juices from six cider apple varieties (sweet cider apples: Coloradona, Verdialona; sharp cider apples: Durona de Tresali, Xuanina, Raxao, Solarina) was analysed in Spain (Blanco-Gomis *et al.*, 2002). Ten fatty acids were quantified, with palmitic and stearic acid being the main ones. The unsaturated oleic and linoleic acids and the saturated caprylic, capric, stearic and palmitic acids were associated with the sweet cider apple category, while pentadecanoic acid was related to the sharp category (Blanco-Gomis *et al.*, 2002).

Another study was conducted to determine the phenolic profile of 46 Spanish cider apple varieties, and paid particular attention to chlorogenic acid content (Mangas *et al*., 1999). Chlorogenic acid is the main substrate for polyphenol oxidase; its oxidation gives rise to pigments that can co-oxidise other substances (Amiot et al, 1992). Therefore, cider apple varieties with a low content of chlorogenic acid are more suitable for making apple juice, for minimizing enzymatic browning and for controlling the stability of the final product. The study concluded that certain varieties (Lagar, Loronesa, Casado, Obdulina, Lin and Durona Tresali) are not appropriate for making apple juice. The work also showed that these Spanish cider apple varieties had lower (-)-epicatechin and procyanidin B2 content compared to English varieties (see Lea, 1990a). Even though lower contents of these compounds are advantageous in terms of the stability of cider regarding haze (particles that develop in apple juice because of the ability of proteins, tannins, and starches to aggregate), these polyphenols are also needed because they contribute to the taste of cider and they also control microbiological spoilage, as well as potentially being health-beneficial. Therefore, varieties with very low polyphenol content such as Cristalina, Perezosa, Pera and No Prieta Antigua could promote several faults that can develop in cider as a result of the activities of lactic acid bacteria (Mangas *et al*., 1999).

Price *et al*. (1999) studied the flavonol content and composition of four dessert apple varieties (Granny Smith, Cox's Orange Pippin, Jonagored, Egremont Russet), one cooking (Bramley's Seedling) and three cider making (Dabinett, Michelin, Yarlington Mill), as well as the distribution of these compounds in pomace and juice of the cider apple varieties, and between peel and flesh in the dessert and cooking varieties. The major flavonol components of all eight apple varieties studied were the following five quercetin glycosides: hyperin, isoquercitrin, reynoutrin, avicularin and quercetin. The total flavonol contents in all eight varieties ranged from 26.4 (Egremont Russet) to 73.9 (Jonagored) μg/g fresh weight (expressed as aglycone). Hyperin was the major component in all varieties apart from Egremont Russet and Jonagored where quercetin predominated and the cider apples where avicularin predominated. In all the dessert and cooking varieties the great majority of the flavonols was concentrated in the peel rather than the flesh. These values ranged from 63.0% (Egremont Russet) to 97.1% (Granny Smith). In the case of cider apples only 9.9 to 12.7% of the flavonols was found in the juice, with the rest remaining in the pomace. The flavonol content of the juice was 4.3, 3.2, 5.0 μg/g fresh weight and that of the pomace 112.9, 87.0, 103.0 μg/g fresh weight for Dabinett, Michelin and

Yarlington Mill respectively. The general conclusion that in the case of juicing the majority of the flavonols are retained in the pomace indicates that the pomace is potentially a rich source of flavonols.

A study was conducted in Canada to assess the polyphenolic composition of selected advanced apple breeding genotypes for cider processing, in comparison to those used in commercial cider production. The highest polyphenol content was found in McIntosh Summerland and Spartan (in peel and flesh respectively) and the lowest in SJCA16R5A15 (in both peel and flesh). Procyanidins were the major class of phenolic for all genotypes studied in both the peel (40.0%) and the flesh (53.4%). The total procyanidins ranged from 119 (McIntosh) to 300 (SJC658) μg/g fresh weight in the flesh and 452.2 (SJCA16R5A15) to 920.3 (Gala) μg/g fresh weight in the peel. Epicatechin and procyanidin B2 were the predominant procyanidins found in both the flesh and the peel in all genotypes (Khanizadeh *et al*., 2008).

The major cider apple cultivars grown in France (Avrolles, Bedan, Kermerrien, Dous Möen, and Petit Jaune) were analyzed for their polyphenol profile (cortex and juices) with variety being the most important variability factor (Guyot *et al*., 2003). In all apple varieties procyanidins were the main phenolic compounds with values from 49% (Dous Möen) to 86% (Avrolles). The varieties also showed significant levels of caffeoylquinic acid and (-)-epicatechin (Guyot *et al*., 2003).

According to a number of studies the phenolic profile of ciders is similar to that of the apples used to make them. The following question, however, is whether the phenolic compounds contained in cider are absorbed by humans so that cider can contribute to the dietary intake of phenolics. A study was conducted in the UK to examine the uptake of polyphenols from a cider when consumed at normal dietary levels (DuPont *et al*., 2002). Blood analysis showed that phloretin was not found in plasma, but 21 ± 5% of the dose was excreted in the urine. Also, no quercetin was detected in both the plasma and urine when taken up at low doses. In terms of flavonols monomers, (+)-catechin and (-)-epicatechin were not detected in plasma or urine and caffeic acid was found only in plasma. Therefore, the authors concluded that polyphenols from alcoholic apple cider are absorbed by humans, phloretin is excreted in the urine and that quercetin at low levels is methylated in humans.

Another study was conducted by Marks *et al*. (2007b) to address the issue of whether the high phenolic content of cider apples is transferred to ciders. For this purpose 23 commercial bottled English ciders were analyzed. Seventeen phenolic compounds were quantified and the authors identified four groups of compounds: flavan-3-ols, hydroxycinnamates, flavonols and dihydrochalcones with the hydroxycinnamates being the major group in most of the ciders. The total phenolic content of the ciders ranged from 44 to 1559 mg/L. This great variation in terms of their phenolic profile, and the analysis of ciders made from a single variety, showed the importance of choosing a variety rich in phenolics in order to produce a phenolic-rich cider; ciders and cider apples have similar phenolic profiles except that ciders have less flavonol glycosides and also the presence of free caffeic acid, p-coumaric acid, quercetin and phloretin. Comparing two single variety ciders (cider 5 produced from Cox apples and cider 4 from Somerset Redstreak apples) it was found that cider 5 had a lower phenolic content (44 mg/L) compared to cider 4 (1559 mg/L), which showed that the final phenolic content of the cider could be influenced by the choice of apples. The authors concluded that choosing an apple variety with high phenolic content might help to produce phenolic-rich cider with potentially increased health benefits (Marks *et al*., 2007b).

Apart from the choice of apple, another factor than may significantly affect the phenolic content of the cider is the making process. Quercetin glycosides, for example are mainly found in the peel; however, Marks *et al*. (2007b) in their study found a minor contribution of these compounds to the final product. The authors therefore suggested that the methods used currently for the production of cider do not efficiently extract phenolics from the peel, and proposed that changes in the cider-making process could potentially produce a final product richer in phenolics. A study was also conducted in France to evaluate the effect of alcoholic fermentation on the phenolic content of five cider apple varieties (sweet: Douce Coët Ligné; acid: Petit Jaune, Guillevic; bitter-sweet: Dous Moen; bitter: Kermerrien). The initial content of phenol compounds in the apple juice ranged from 188.4 to 2776.2 mg L^{-1}. Dous Moen and Kermerrien had the highest phenol content, while Petit Jaune and Guillevic had the lowest. Fermentation had no effect on the total content of phenol compounds in Douce Coët Ligné, Petit Jaune and Guillevic, but it reduced the values in Dous Moen and Kermerrien by 55 and 313 mg L^{-1} respectively. The values of caffeic acid and catechin were also affected during the fermentation process, while all the other phenol classes did not show any modification. In Kermerrien the caffeic acid content increased from 6.6 to 41.8 mg L^{-1} and in Dous Moen the catechin increased from 24.7 to 37.4 mg L^{-1} (Nogueira *et al*., 2008).

Finally, in terms of factors affecting the phenolics of ciders, Lea and Beech (1978) found that trees fro traditional orchards were capable of producing fruit with higher phenolic levels which might be explained by the lower levels of nitrogen fertilizers applied compared to the modern intensive systems.

Another question is whether cider phenolics survive pasteurisation. The ciders in the study by Marks *et al*. (2007b) were bottled, therefore pasteurised, which implies that phenolics do survive the process of pasteurisation. However, the fact that pasteurisation in ciders takes place at 60^{o}C for 50 minutes (Duffy and Shaffner, 2001) suggest that this could result in some phenolics being lost. Al-Turki *et al*. (2008) recently analysed the phenolic contents and antioxidant capacities of fresh juice from a range of cultivars and species and concluded that whilst pasteurisation had no effect on polyphenolic content it did significantly reduce antioxidant activity.

Development of new varieties and available genetic resources

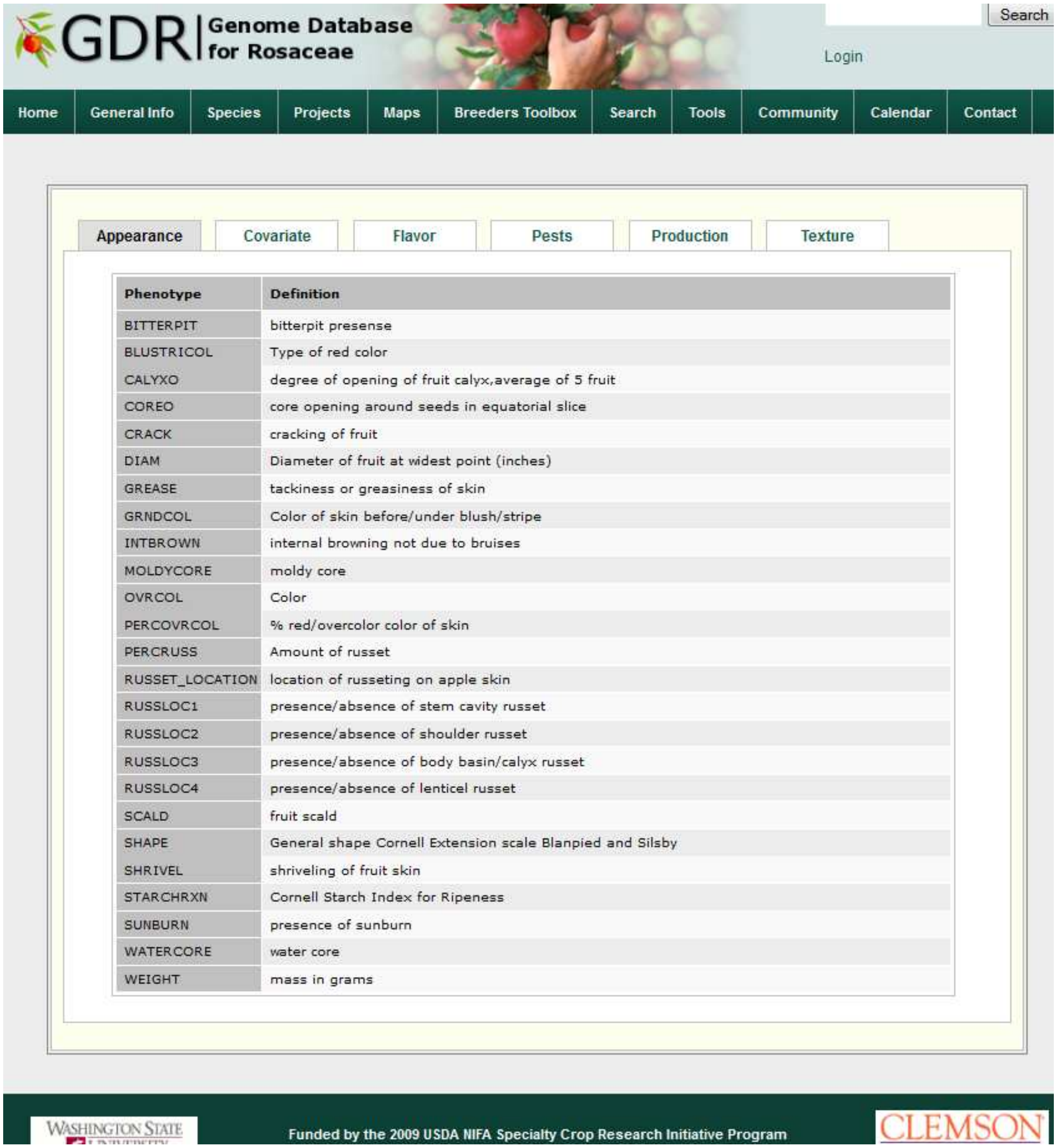
Development of new varieties will require the identification of traits and the genetic controls of key characteristics. The last rounds of breeding work from Long Ashton Research Station (as described by Copas, 2010) focused on developing varieties with earliness to address a largely logistical problem of the glut of mid-season apples due to the industry reliance upon mid-season varieties caused by the under-performance of many of the available early varieties. The work aimed to combine earliness, fruit size and good tree habit from the dessert varieties James Grieve and Worcester Pearmain, with the classical cider producing traits of Michelin and Dabinett. Twenty-nine selections offering a range of bittersweet, bittersharp and sharp varieties were selected from this program and are being used in ongoing tests.

Traits from the wider apple genetic resources offer opportunities to develop other new varieties in the future, in order to address the challenges highlighted in this review. This approach is discussed further in Part 3. Here we note that the available cider apple resources are as follows. Alongside a collection of approximately 2,000 culinary and dessert varieties, the National Fruit Collection at Brogdale holds a selection of 97 cider specific varieties (many of which were supplied from the collection at Long Ashton Research Station). These are detailed in Appendix 3 along with some information on flowering time and picking season, which range from April 19th - May 24th and August - November respectively. Further descriptions of these varieties are available within the NFC database (www.nationalfruitcollection.org.uk as well as in a variety of published works, including Copas, 2001). Further collections of cider varieties in the UK include local varieties held by the Gloucestershire Orchard Group (http://www.gloucestershireorchardgroup.org.uk/) and a collection of approximately 400 varieties relating to cider making at Tidnor Wood Orchard which include a mixture of classical cider varieties and some multipurpose varieties used as 'sweet' and 'sharp' varieties for cider production. Merwin *et al.* (2008) summarized the current situation of cider in France, Spain, the UK and USA. The authors describe a collection of 1,000 cultivars at INRA, France (highlighting 350 with published descriptions and about 70 'elite' cultivars that were then recommended for cider production in France); the authors also list a further 20 Asturian cider apples which represent the main varieties grown in Spain; and they list germplasm repositories within Spain containing 1,200 local and international accessions, many of which have been used in cider production. A review of the USDA genetic resources indicates that several hundred accessions are held in the collections in Geneva, NY although the cider varieties amongst these are suggested to largely consist of English, French and Spanish cultivars. In terms of the wider species diversity, individual examples of *Malus* species are held within many botanical gardens, no accessions of *Malus pumila* are held within the UK Millenium Seed Bank, Kew at the time of writing, although within the USDA collections approximately 570 accessions of *Malus sieversii* (synonymous to *Malus pumila* - see above for taxonomic discussion) are held within either scion or seed collections and wider resources are held around the centre of origin.

1.5.3 New techniques for apple breeding

There has been much recent progress in understanding and exploiting the genome sequence of apple. It has a large, heterozygous genome (Jensen *et al*., 2010), approximately 1,000 Mb in size (Han *et al*., 2007). Much of the genomic data for apple is available in the Genome Database for Rosaceae (http://www.rosaceae.org/), a website funded by the USDA Speciality Crops Research Initiative. Among the many resources at this site is the "Breeders Toolbox" which will provide access to phenotype and genotype data for rosaceous crops including apple. It is being developed using funds provided by the USDA NIFA SCRI funded "tfGDR" project, USDA NIFA SCRI

"RosBREED" project and Washington Tree Fruit Research Commission "Tree Fruit Breeders Online Toolbox" project. At the current time, the toolbox provides access to standardized phenotype data (see Figure 6 for criterion “appearance”) collected in 2010 for 494 apple cultivars from the RosBREED Apple Crop Reference Set.



Phenotype	Definition
BITTERPIT	bitterpit presense
BLUSTRICOL	Type of red color
CALYXO	degree of opening of fruit calyx,average of 5 fruit
COREO	core opening around seeds in equatorial slice
CRACK	cracking of fruit
DIAM	Diameter of fruit at widest point (inches)
GREASE	tackiness or greasiness of skin
GRNDCOL	Color of skin before/under blush/stripe
INTBROWN	internal browning not due to bruises
MOLDYCORE	moldy core
OVRCOL	Color
PERCOVRCOL	% red/overcolor color of skin
PERCRUSS	Amount of russet
RUSSET_LOCATION	location of russeting on apple skin
RUSSLOC1	presence/absence of stem cavity russet
RUSSLOC2	presence/absence of shoulder russet
RUSSLOC3	presence/absence of body basin/calyx russet
RUSSLOC4	presence/absence of lenticel russet
SCALD	fruit scald
SHAPE	General shape Cornell Extension scale Blanpied and Silsby
SHRIVEL	shriveling of fruit skin
STARCHRXN	Cornell Starch Index for Ripeness
SUNBURN	presence of sunburn
WATERCORE	water core
WEIGHT	mass in grams

Fig. 6: Example of phenotypic data available for selected cultivars at http://www.rosaceae.org/breeders_toolbox/desc_phenotype

The cultivars can be browsed; searched by name, traits, parentage; and the data downloaded as an input file for pedimap (Appendix 4) or as an excel file in wide or long format. Such data are being utilized in many breeding programmes around the world.

Apple has an extended juvenile stage, which may last for 4-8 years or longer (Tränkner *et al*., 2010). Even though there are traits (e.g. resistance to apple scab and powdery mildew) which can be tested on young apple trees, many (e.g. fruit firmness, flavour, shelf life) can be tested only on the fruit (Tränkner *et al*., 2010), or involve flowering and must therefore be evaluated on mature trees. These are all constraints that make conventional breeding and genetic analysis of apples difficult. However, the use of marker-assisted breeding (MAB) and marker-assisted selection (MAS) can potentially reduce these problems. MAB has been defined as 'the use of markers to assist in one or more operations of breeding programmes, such as parent selection, family size planning, parentage verification, seedling selection, performance evaluation of advanced selections, and cultivar commercialization'; while MAS is 'the use of markers for selection in breeding-both of parents and seedlings, but usually referring to seedlings' (Peace and Norelli, 2009). In addition, map-based approaches can be used to identify and clone several apple genes of commercial interest (Han and Korban, 2010).

Marker-assisted seedling selection is in use for scab and powdery mildew resistance in apples (Kellerhals *et al*., 2004). Markers for the V_f gene from *M*. *floribunda* 821 have been found and the V_f gene has been introduced into susceptible cultivars to provide scab resistance (Barbieri *et al*., 2003). A number of other scab resistance genes are known and these include the *Vh2*, *Vh4*, *Vm*, *Va*, *Vbj*, *Vb*, *Vd*, and *Vr2* genes (Patocchi *et al*., 2009). Even though these genes have been known for a long time (Williams and Kuc, 1969), Patocchi *et al*. (2009) state that only a few cultivars have been released, 'Murray' and 'Rouville' with the *Vm* gene, 'Regia' with the *Vh4* and 'Durello di Forlì' with the *Vd* gene. Markers have also been developed for these other resistance genes. Cheng et al. (1998) refers to the *Vm* gene for resistance to race 5 of scab. V_r and V_x genes from the Russian seedling R12740-7A have been identified and markers were developed (Hemmat *et al*., 2002). There are also markers for resistance to powdery mildew (Dunemann *et al*., 1999; Phillips *et al*., 2000). The latter authors developed molecular markers linked to mildew resistance genes *Pl-w* and *Pl-d* derived from the 'White Angel' and 'D12'

Malus selections respectively and identified several fragments likely to be linked to *Pl-w* and *Pl-d*.

In terms of insect pests, the genes involved in the resistance of plants to aphids have been identified and characterised in very few plant species. Experimental work has been undertaken to identify the genes involved in resistance or susceptibility against the rosy apple aphid (Qubbaj *et al*., 2005). The method employed here for gene expression analysis was cDNA-AFLP (cDNA-Amplified Fragment Length Polymorphism). For the purposes of the study a susceptible ('Topaz') and a resistant cultivar ('Florina') were used and three genes responsible for the resistance of the apple trees against the rosy apple aphid were identified; information which could be used for the development of markers in a MAS breeding program of apple cultivars resistant to aphids. Bus *et al*. (2008) reported molecular markers for three major resistance genes to woolly apple aphid (WAA). In their study, Bus *et al*. identified genetic markers linked to the *Er1* and *Er3* genes and these were evaluated for their potential use in MAS for selection of apple cultivars resistant to WAA. This work has been extended in a subsequent publication (Bus *et al*., 2010).

Quantitative trait locus mapping of resistance in apple to codling moth and an apple leaf miner has been carried out by Storeckli *et al*. (2009) on 160 apple genotypes in Switzerland. Although no significant QTL was identified for resistance to the leaf miner, one possible one was found for the codling moth, linked to fruit number, which the authors suggest may facilitate breeding resistant cultivars with good cropping traits.

A study was conducted to identify quantitative trait loci (QTL) for time of initial vegetative budbreak (van Dyk *et al*., 2010). Genetic maps were constructed from two F_1 crosses using one low chilling ('Anna') and two higher chilling ('Golden Delicious' and 'Sharpe's Early') cultivars as male and female parents respectively. The maps were then used for the identification of QTL for time of initial vegetative budbreak, a characteristic related to dormancy. One single QTL was identified on linkage group (LG) 9, which explained up to 40.1 and 44.6% of the phenotypic variation in the F1 progenies derived from the cross between 'Anna' and 'Golden Delicious' and 'Anna' and 'Sharpe's Early' respectively. Lawson *et al*. (1995) and Conner *et al*. (1998) also used molecular-marker analysis to estimate quantitative traits which influence juvenile tree growth and development in apples (i.e. timing of vegetative and reproductive bud flush).

The MAS system could also be used in a columnar-type apple breeding program as developed by Moriya *et al*. (2009). Such breeding programmes for columnar-type seedlings started in Japan at the National Institute of Fruit Tree Science (NIFTS) in 1987. Columnar-type seedlings have the advantage of being labour saving because they require minimal pruning and training, since they are characterized by compact growth habit. The columnar growth habit in apples was found in 'Wijcik', which is a bud mutant of McIntosh (Fisher, 1970). However, because the poor fruit quality of 'Wijcik' was an issue for growers and consumers, breeders crossed 'Wijcik' with known apple cultivars of good fruit quality (e.g. 'Fuji') (Moriya *et al*., 2009). According to Lapins (1976) the columnar character was mainly determined by the *Co* gene. Several columnar-type selections from Canada were used as donors of the *Co* gene instead of trying to improve the fruit quality of 'Wijcik', a practice which would take many years. A MAS system was developed for columnar growth habit in apple breeding in Japan (Moriya *et al*., 2009). Genetic linkage maps of the *Co* genomic region were developed and DNA markers were identified for selection of seedlings with columnar growth habit. The results showed that CH03d11 was the most suitable marker to select between columnar and non-columnar phenotypes using a MAS system.

Another example of the use of marker assisted selection as applied to a physiological trait is associated with fruit ripening. In a project at the Washington apple breeding programme (WABP) two markers were identified for fruit with 90% less ethylene production (Costa *et al*., 2010). This is a desirable trait for apples because it will delay the ripening process and protect the fruit from bruising during transportation to the stores (Kean, 2010). In the final project report (Peace, 2011) it is stated "The ethylene genes *Md-ACS1* and *Md-ACO1* are the first markers to be validated and converted into routine genetic tests for the WABP. This year, by spending $10,000 on genetic screening, marker-assisted seedling selection provided an estimated net savings of $62,000 in present and future costs for the WABP." Their approach to integration of markers into a breeding programme is given in Figure 7.

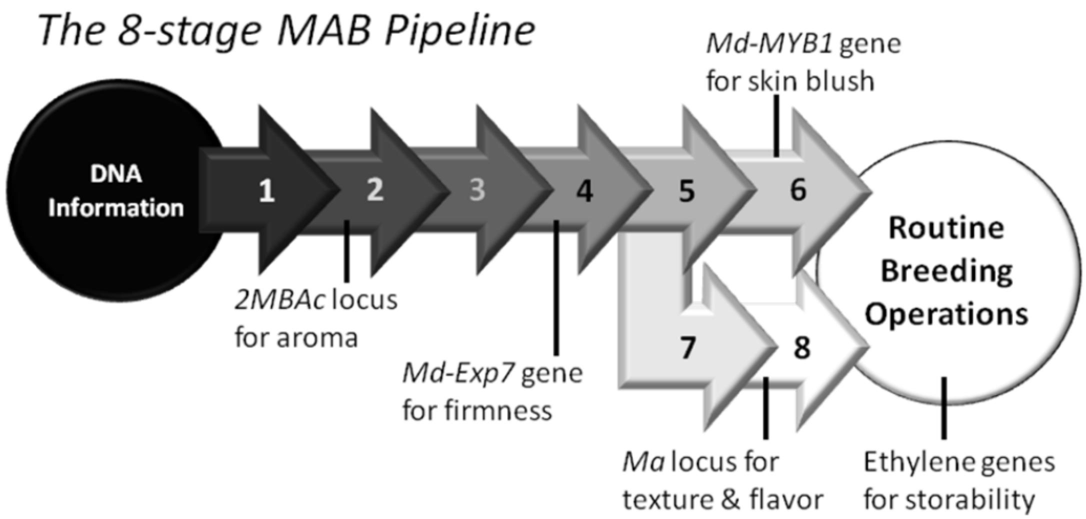


Fig. 7: Current status of translating reported DNA information into routine applications in the Washington apple breeding program. The breeding "outlet" from stage 6 involves DNA-informed crossing decisions, while the breeding outlet from stage 8 is for seedling selection (Peace, 2011)

Several other related studies have been undertaken on fruit quality. For example, a detailed description of QTLs linked to fruit texture traits is provided in a recent thesis (McKay, 2010) based on analysis of the popular US variety Honeycrisp and a study (Nobile *et al*., 2011) has identified an α-L-arabinofuranosidase gene associated with mealiness in apple. Most recently, Dunemann *et al*. (2011) studied single nucleotide polymorphisms (SNPs) in a candidate gene alcohol acetate transferase (AAT) involved in the last step of ester biosynthesis that determines the production of ethyl esters, the most important volatile compounds in apple. They used association analyses and found highly significant associations of both individual SNPs and distinct haplotypes with the content of four acetate esters, including hexyl acetate, butyl acetate and 2-methyl-butyl acetate. A related study found a probable relationship between the activity of the enzyme MdCXE1, a carboxylesterase that is expressed during fruit ripening, and flavour esters (Souleyre *et al*., 2011).

MAS is also being used to define genetically biennial bearing, with the long-term aim of breeding dessert apple cultivars less susceptible to the problem (Celton *et al*., 2011; Guilton *et al*., in press). A further element of work on molecular markers was carried out by East Malling Research within Defra project HH3604STF which focused on the development of a molecular map for top fruit rootstocks with an extension of markers to cover cider traits although due to low variation within the material studied for phenolic content, markers were pursued for the columnar habit donated from Wijcik McIntosh.

Single gene markers and strategies for breeding for pest/disease resistance

Although at least eight genes for resistance to apple scab exist, the majority of the commercial scab resistant cultivars owe their resistance to the V_f gene from *Malus floribunda* 821 (Crosby *et al*., 1992). However, since this resistance was overcome in Northern Europe (Parisi *et al*., 2004), breeders have started searching for alternative resistance sources to incorporate in their breeding programmes. Apparent scab resistance has often been due to single 'R-type' genes, to which the corresponding virulence can rapidly become common once the variety is released. Recently, research has been undertaken on 'pyramided' resistance, where different resistance genes are combined. However, since *V. inaequalis* is a fully sexual organism even rare combinations of virulence are likely to be generated rapidly unless many different R-genes, all with rare corresponding virulence, are simultaneously incorporated. This is very unlikely to be practical for cider varieties, and the longer term aim must be to breed polygenic resistance, avoiding known R-genes.

The two main genes that have been used in breeding apple resistant rootstocks to WAA are *Er1* and *Er2* derived from 'Northern Spy' and 'Robusta 5' respectively. *Er3* from 'Aotea 1' is referred to as a relatively new major WAA resistance gene. However, all three *Er* resistances have been overcome (Sen Gupta and Miles, 1975; Cummins and Aldwinckle, 1983; Sandanayaka *et al*., 2005). Again, these single-gene resistances were not durable and MAS is important for the identification of alternative sources of resistance or pyramided resistance in order to achieve durable resistance to WAA (Bus *et al*., 2008).

In most cases of 'resistance' breeding the aim is overall disease resistance and resistances against powdery mildew (*Podosphaera leucotricha*) and fireblight are also incorporated (Kellerhals *et al*., 2009). For example, a breeding program was undertaken in Belgium for the development of high quality commercial apple varieties resistant to scab, powdery mildew and *Nectria* canker (Lefrancq *et al*., 2004). The breeding program was using old apple cultivars and land-races as parents (e.g. an old English cider apple 'Brown's Apple' and the cultivar 'Mosanceli') with low disease susceptibility and high quality characteristics. The new resistant varieties that were expected to be bred, however, will probably incorporate R-gene resistance and will be subject to breakdown, as happened with varieties incorporating the resistance V_f (Guérin, 2007).

Haploid breeding

One important technique with potential in breeding of many crops is the isolation and exploitation of haploid and doubled haploid plants (Dunwell, 2010). Such doubled haploids are completely homozygous and can be used directly in QTL mapping programmes or as the potential parents in the production of F_1 hybrids. Although there have been several attempts to generate haploids in apple either from spontaneously produced abnormal embryos or from anther/ovule culture, they have not yet been integrated into large scale breeding projects (Germana, 2006; Hoefer *et al*., 2008; Okada *et al*., 2009).

Transgenic techniques

There are also several opportunities in the area of apple breeding using transgenic approaches (Gessler and Patocchi, 2007). Genetic transformation technology was first applied to the apple cultivar Greensleeves (James *et al*., 1996). The transformation methods used currently rely on the use of *Agrobacterium*-mediated transformation systems (Yongjie *et al*., 2011) and some of these use selectable marker genes.

There are certain potential limitations of the transgenic technology. The use of marker genes, in particular those encoding antibiotic resistance, in crop plants has raised some concerns about their possible horizontal transfer to other bacteria (Flavell *et al*., 1992; Fuchs *et al*., 1993). For transgenic crop plants to gain public acceptance, the use of such marker genes should be discouraged, and this is the policy of all relevant regulatory authorities. It should be noted, however, that antibiotic resistance genes are common in most soils, including those of orchards (Donato *et al*., 2010).

There are several ways to produce marker-free transgenic plants. For example, Malnoy *et al*. (2010) developed a technique in apples that avoids a selectable marker gene by using constructs that express a blue colour marker. However, this technique has disadvantages, including low transformation efficiency (12-25% depending on the cultivar), which is 25-30% of the efficiency with the use of kanamycin resistance as a marker. Although the low transformation efficiency, was not an insuperable problem with the two genotypes studied (M. 26 and Galaxy), it could be an issue with other cultivars such as Golden Delicious, Pink Lady and Pinova which are more difficult to transform (Schaart *et al*., 1995; Sriskandarajah and Goodwin, 1998; Hanke *et al*., 2000).

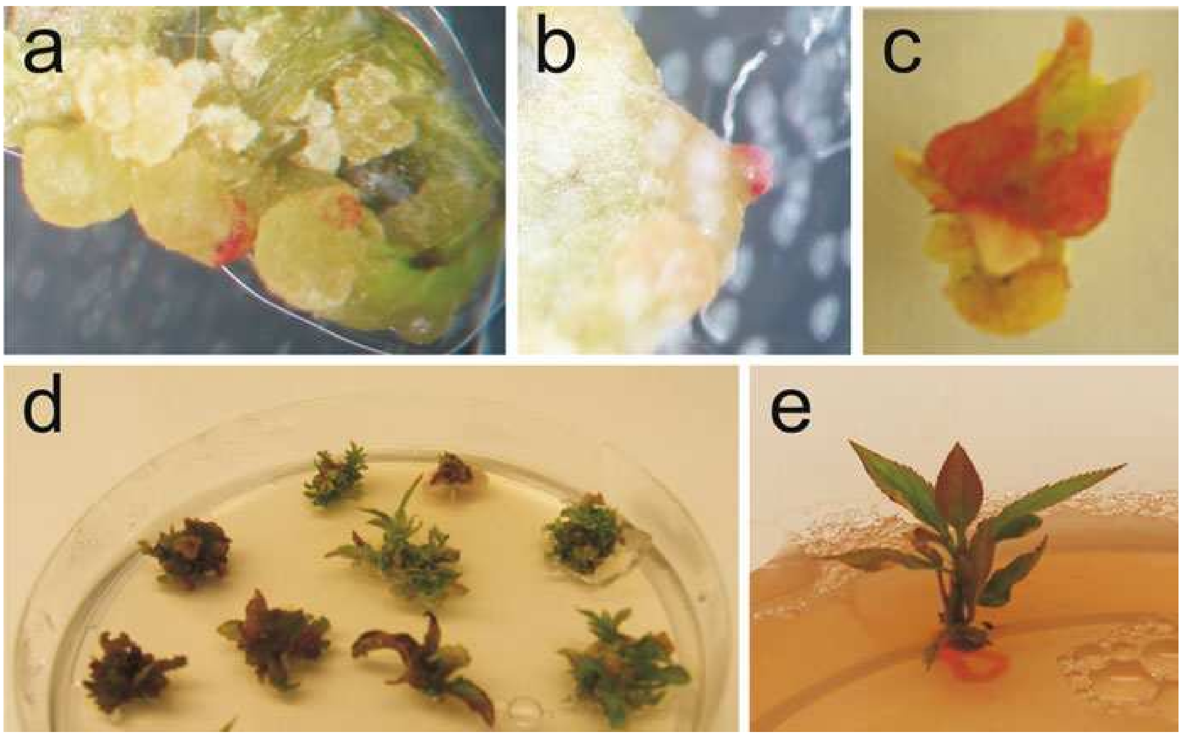


Fig. 8: Anthocyanin accumulation at different stages of apple regeneration. a and b: calli on explants transformed with the MYB10 gene construct 4–8 weeks after transformation. c: shoot-like structure forming on a callus, approximately 12 weeks after transformation. d: regenerated shoots on explants on a Petri dish, 12–16 weeks after transformation and e: a regenerated plantlet on propagation medium, 20 weeks after transformation (from Kortstee *et al*., 2011)

A similar recent development exploited the use of a mutant allele of the transcription factor gene MYB10 from apple that induces anthocyanin production throughout the plant. This gene, including its upstream promoter, gene coding region and terminator sequence, was introduced into apple (Figure 8) and shown that it could be used as a visible selectable marker for plant transformation as an alternative to chemically selectable markers, such as kanamycin resistance.

Disease and pest resistance

A review of the various transgenic apple programmes conducted over the last 10-15 years shows that most are associated with disease resistance. For example Krens *et al*. (2011) have recently reviewed encouraging results from four years of field trials of various lines expressing the barley hordothionin gene, which gives improved tolerance to apple scab. In a related programme it was shown that transgenic apple (*Malus* x *domestica* cv. 'Holsteiner Cox') overexpressing the *Leaf Colour* (*Lc*) gene from maize (*Zea mays*) exhibit strongly increased production of anthocyanins and Xavan-3-ols (catechins, proanthocyanidins). In tests, this material showed higher resistance against fireblight (caused by the bacterium *Erwinia amylovora*) and against scab (caused by the fungus *Venturia inaequalis*) (Flachowsky *et al*., 2010b). An assessment of the possible non-target impact of scab resistant material was conducted by Vogler *et al*. (2010) who tested the volatile emissions from transgenic and control material during insect exposure and showed no significant differences.

Borejsza-Wysocka *et al*. (2010) described results from transgenic apple trees that expressed attacin E, an antimicrobial protein from the moth *Hyalophora cecropia*, and field resistance to fireblight without any adverse effect on fruit quality (Figure 9).

TGx-158 TGx-178 Galaxy

TGx-158 Galaxy

Fig. 9: Fruits and tree from transgenic lines (TGx158 and TGx178) and control ('Galaxy') (Borejsza-Wysocka *et al*., 2010)

Preliminary details of a project to address novel approaches to insect resistance are given in a recent thesis (Magalhaes, 2011).

Abiotic stress tolerance

The C-repeat binding factor (CBF/DREB) transcriptional activator genes are able to induce the expression of a suite of genes associated with increased cold tolerance. In a recent study a full-length cDNA of a peach CBF gene, designated PpCBF1, was isolated and constitutively expressed in apple using an enhanced 35S promoter (Wisniewski *et al*., 2011). Unexpectedly, this constitutive overexpression resulted in strong sensitivity to short daylength. Growth cessation and leaf senescence were induced in transgenic lines exposed to SD and optimal growth temperatures of 25^{o}C over a 4-week period. Following 1–4 weeks of SD and 25^{o}C trees were returned to LD and 25^{o}C in the greenhouse. Control (untransformed) plants continued to grow while transgenic lines receiving two or more weeks of SD remained dormant and began to drop leaves. Constitutive overexpression also resulted in a 4–6^{o}C increase in freezing tolerance in both the non-acclimated and acclimated states, respectively, compared with untransformed M.26 trees. The authors claim that this is the first instance that constitutive overexpression of a CBF gene has resulted in SD-induction of dormancy and to their knowledge the first time apple has been shown to strongly respond to short daylength as a result of the insertion of a transgene.

Among the chloroplast proteins that have been linked to stress tolerance and disease resistance are the fibrillins, with FIBRILLIN4 (FIB4) found to be associated with the photosystem II light-harvesting complex, thylakoids, and plastoglobules. It has been shown recently that down-regulation of the *fib4* gene in apple led to plants with greater sensitivity to high light and other photooxidative stress and confirmed the significance of this protein in broad stress sensitivity (Singh *et al*., 2010).

Vacuolar H+-translocating inorganic pyrophosphatase (VHP, EC 3.6.1.1) is an electrogenic proton pump, which is related to growth as well as abiotic stress tolerance in plants. In a recent study, a VHP gene MdVHP1 was isolated from apple (Dong *et al*., 2011). MdVHP1 overexpression enhanced tolerance to salt, PEG-mimic drought, cold and heat in transgenic apple calluses; this response was related to an increased accumulation of proline and decreased malondialdehyde content compared with control calluses. These results indicate that MdVHP1 is an important regulator for plant tolerance to abiotic stresses by modulating internal stores of ions and solutes. Such evidence may have value is designing future transgenic approaches to improve tolerance to abiotic stress (es).

Plant phenotype

Intensive work is in progress to shorten the juvenile stage and control the time of flowering by altering the expression of floral genes in apple. Flachowsky *et al*. (2007, 2011) for example showed that over-expression of the gene BpMADS4 from silver birch (*Betula pendula* Roth.) shortened the juvenile stage and induced flowering in apple in vitro. In an attempt to remove the juvenile stage of apple, Flachowsky *et al*. (2010a) transferred the *LEAFY* gene of *Arabidopsis* into the genome of an apple cultivar. This over-expression, however, resulted in transgenic plants with a columnar phenotype. In another study the flowering of apple seedlings was promoted by ectopic expression of the *Arabidopsis thaliana* FT genes using the Apple Latent Spherical Virus vector (ALSV). The apple seedlings flowered two months after germination and the next-generation seeds were produced within seven months (Yamagishi *et al*., 2011).

Another series of studies have examined the effect of expressing genes from *Agrobacterium rhizogenes* that affect adventitious rooting. Such an approach may have value in modifying the performance of root stocks. A recent publication reported results from a field trial on three *rolB* transgenic dwarfing apple rootstocks of M26 and M9 together with non-transgenic controls grafted with five non-transgenic scion cultivars (Figure 10) (Smolka *et al*., 2010). The study was designed to investigate the effects of transgenic rootstock on non-transgenic scion cultivars under natural conditions as well as to evaluate the potential value of using the *rolB* gene to modify difficult-to-root rootstocks of fruit trees. It was concluded that all *rolB* transgenic rootstocks significantly reduced vegetative growth including tree height regardless of scion cultivar, compared with the non-transgenic rootstocks.

Fig. 10: Overview of the field trial in Alnarp, Sweden, established in 2001. The trees consist of transgenic rootstocks grafted with non-transgenic cultivars (Smolka, 2009)

In an additional series of tests, the fruit quality was analyzed for the cultivars Elise, Elstar and Jonagold grafted on one *rolB* transgenic clone of rootstock M26 and two transgenic clones of M9 with the *rolB* gene, named *rolB*1 and *rolB*2, as well as non-transgenic M26 and M9 as controls (Muneer, 2010). Quality parameters analyzed include fruit size, fruit weight, fruit colour, firmness, acidity (TA), total soluble solids (TSS) and ratio of TSS to TA, vitamin C and total phenols. Among the findings were that Elise on M26 and M26 (*rolB*) had a greater size than those on transgenic and non-transgenic M9. The amount of acidity of Jonagold on M26 (*rolB*) was significantly higher as compared to M26. M26 (*rolB*) had higher TSS in Elise than non-transgenic M26, M9 and transgenic M9 (*rolB*1). The fruit firmness was significantly higher in M9 and M9 (*rolB*2) both in the case of Elise and Elstar than non-transgenic M26, M9 and transgenic M9 (*rolB*1).

Fruit quality

Dandekar *et al*. (2004) and Hrazdina *et al*. (2003) produced transgenic apples in which ethylene production was modified by suppression of the activity of 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase (ACO) or ACC synthase (ACS); these trees produced firmer fruit with improved shelf-life. It was also shown that anti-sense suppression of ACO resulted in fruit with an ethylene production sufficiently low to be able to assess ripening in the absence of ethylene (Johnston *et al*., 2009). The storage characteristics of such fruit and the incidence of scald are described in Pesis *et al*. (2009). There have also been efforts to use transgenic techniques to reduce the allergenicity of apple by silencing of the major allergen Mald1 (Gilissen *et al*., 2005; Krath *et al*., 2009; Schenk *et al*., 2011).

Field trials

The major source of information on field trials of transgenic crops in the USA is the Information System for Biotechnology available at http://www.isb.vt.edu/data.aspx. This shows a total of 64 applications for transgenic apple from 1991 to the present day. Data for the most recent 10 are given in Table 3 which shows most the trials involve trees with reduced browning, modified ethylene production or altered sorbitol levels. There is one trial of material with altered cold tolerance. Similar data for the European Union are given in Table 4 which shows a much smaller number of trials.

Table 3: Summary of recent US field trial applications for transgenic apple (from http://www.isb.vt.edu/data.aspx)

NUMBER	INSTITUTION	ACRE	TRAIT
11-188-102r	Univ. California/Davis	3.5	Reduced ethylene/decreased sorbitol
11-056-102r	CBI	1	Reduced polyphenol oxidase
11-067-105r	Cornell Univ.	0.5	Reduced polyphenol oxidase
10-189-116r	CBI	1	Reduced polyphenol oxidase
10-146-104n	Cornell Univ.	1	Decreased sorbitol
10-078-102r	USDA/ARS	0.5	Increased and decreased cold tolerance
10-070-103n	USDA/ARS	0.05	Increased and decreased cold tolerance
09-139-102n	Cornell Univ.	1	Decreased sorbitol
08-235-102r	Univ. California/Davis	3.5	Reduced ethylene, altered sorbitol
08-128-105n	Cornell Univ.	1	Decreased sorbitol

Table 4: Most recent applications for field trials of transgenic apples in the European Union (from http://gmoinfo.jrc.ec.europa.eu/gmp_browse.aspx)

NUMBER	COUNTRY	DATE	ORGANISATION	TRAIT
B/NL/10/05	Netherlands	30/03/2011	DLO	Scab resistant cisgenic
B/SE/09/12183	Sweden	28/01/2010	Dept Plant Breeding Biotechnology, Alnarp	Effects of transgenic apple rootstocks M26 and M9 on growth characteristics of 5 apple cultivars in comparison with the non-transgenic rootstocks
B/NL/04/02	Netherlands	24/02/2005	PRI	Evaluation of non-flowering trees with increased resistance to fungi
B/DE/03/140	Germany	02/09/2003	Fed Centre for Breeding Research	Research on Cult Plants characteristics and their stability in GM trees

Commercialisation

Probably the most commercially advanced transgenic project in apple is that underway at the Canadian company Okanagan Specialty Fruits (http://www.okspecialtyfruits.com/). Their "Non-browning Apple" project involves the down-regulation of polyphenol oxidase the enzyme responsible for browning when the cut surface of an apple is exposed to air. In their words:- Traditional processors will find non-browning apple juice and sauce can be produced in a manner that allows for the production of apple juices that retain many of the individual taste and color characteristics of each apple variety". To date they have developed non-browning versions of many popular varieties (Gala, Fuji, Golden, Granny, etc.). These have undergone 5 years of field testing, the fruit has been tested and no non-target response has been identified. The company is now producing the data sets required so that it can proceed with deregulating these varieties through the USDA and the FDA.

An associated area of research is that concerning the production of cisgenic and/or intragenic varieties, as an alternative to "transgenic" methods. This alternative approach is led principally by the group in Wageningen who have produced several apples lines by transfer of gene(s) from either sexually compatible *Malus* species (cisgenic) or from within the same species of cultivated apple (intragenic) (Figure 11). The most recent results on the production of scab resistant lines are reported in Joshi *et al*. (2011) and Vanblaere *et al*. (2011). One of the main proposed advantages of such material is that it will prove to be more acceptable to the consumer (Schenk *et al*., 2011) and in this context the US authorities are considering reducing the regulatory burden on these varieties (Reardon, 2011; Waltz, 2011). Specifically, in March 2011, the U.S. Environmental Protection Agency (EPA) opened a request for comments on a draft rule that would exempt cisgenic organisms from the requirement to be registered with the EPA before being field-tested or marketed. The comment period closed on the 15th April, and it is predicted that such a rule change will be approved.

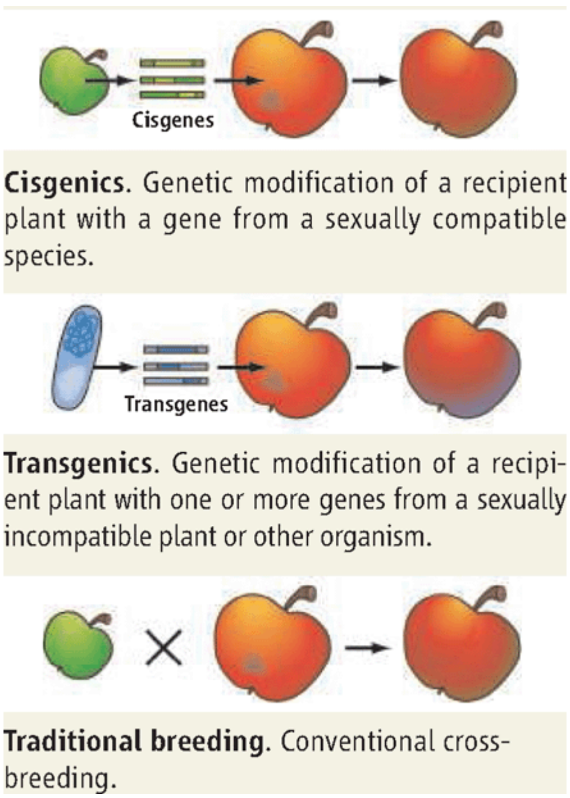


Fig. 11: Definitions of key terms (from Reardon, 2011)

Conclusions

There is increasing evidence suggesting global climate change is taking place. Increases in mean air temperature as a result of the increased atmospheric CO_2 *concentration are projected for the coming decades with significant effects on biological processes such as insufficient chilling, as well as adverse effects on pollination. The exact pattern of temperature change will vary according to geographic location. The breeding of new cultivars adapted to future environmental conditions is therefore essential. Low chill adaptation, lengthened/altered flowering period, reduced biennial bearing, parthenocarpy, fruit phenolic content, and modified growth habit are all traits which could be explored through a cider apple breeding programme. As with much of the literature the focus of current work is on dessert apples but in these aspects much of the technology is transferrable. There are also opportunities available through the production of transgenic plants but the exploitation of these is currently limited by public concerns.*

1.6 Principal disease and pest problems; existing and potential methods for control

The comments on biodiversity in Section 1.2 emphasise that management of pests and diseases must be a management process, not a reactive application of single techniques. Integrated Pest Management (IPM) is therefore crucial, but complex. A number of advisory packages for dessert and culinary apples are available and may have application in the cider sector, though their management cost is high for a crop where inputs are traditionally low.

The main pests and diseases in cider orchards are similar to those in dessert and culinary apples, but the emphasis of management differs because the damage relationships, harvest techniques and drivers of orchard structure differ. The principal fungal diseases of concern are scab, mildew, canker, replant disease, Phytophthora and brown rot; perhaps around 50 other diseases cause problems in some apple production systems in some parts of the world. Fire blight is the only current bacterial disease needing consideration, particularly because its host range can lead to unexpected interactions in the quest for high-biodiversity growing systems. Mycoplasmas are not of current UK concern. Animal pests (excluding pigeons and squirrels) are apple sawfly, aphid species – mainly rosy apple aphid, codling moth and other tortrix moths, spider mites and a wide range of other potentially damaging species. A number of component tactics available for use in IPM systems affect several categories of pests. There are notable interactions among pests and diseases; in particular, insect damage, primarily by apple sawfly, is the main entry route for *Monilinia* brown rot, which can have a very large impact on the usable yield of cider orchards (Berrie and Copas, 2001).

There are two aspects to managing orchards for sustainable outputs of fruit and ecosystem services in the presence of pests and diseases. First, there are pests and diseases which currently require modification of growing systems in order to minimise or eliminate spraying with synthetic pesticides, such as sawfly and scab. Second, there is a need to prepare for small, even rare, populations currently causing at most minor nuisances becoming major problems by ill-judged changes to the growing system or the effects of climate change. To some extent this can be done by comparison with other parts of the world, but the pest spectra of these are not necessarily at equilibrium, and in any case evolution proceeds rapidly in most pest species and it must be assumed that problems will arise and fade over time. A sustainable system has to include an element of active management, monitoring and research as the biology underlying the system changes.

The pest/disease community is dynamic, however, with established minor pests becoming important due to management practices (e.g. fruit tree red spider mite *Panonychus ulmi* with introduction of broad spectrum insecticides in 1950s which killed its predators), new ones becoming established (e.g. fireblight *Erwinia amylovora* first recorded in UK 1957, rapidly spreading since 1969 and now endemic, and *Phytophthora syringae* since 1973). An example of the latter, the spread of which in the UK may be helped in the future by climate change is the light brown apple moth (*Epiphyas postvittana*) (Lepidoptera: Tortricidae), and Australian native that has become established in California and the UK. In the UK it was first recorded breeding in 1936 but only found in coastal Devon and Cornwall. Since the 1990s it has spread rapidly, possibly with nursery stock, and can now be found in much of England, but so far mainly in milder urban areas. It has a very wide host range, including common weeds such as *Rumex* and *Plantago*, which will make control difficult (see Suckling and Brockerhoff, 2010).

Scope for use of resistant varieties

At present scab resistant varieties account for a small percentage of the market (Sansavini *et al*., 2004). A European survey by Kelderer *et al*. (2004) revealed that even countries like Switzerland and Germany with increased ecological awareness and well developed integrated and organic production have no more than 5-6% of the market with scab resistant varieties, while in Italy such varieties account for less than 1% (cited in Sansavini *et al*., 2004). However, this low uptake is partly due to market demands for specific qualities in table and culinary fruit which are not yet available or appreciated in scab resistant varieties. In terms of the appearance of fruit, within cider production, fruit appearance is not so critical (and consumers 'brand loyalty' to varieties is greatly reduced), so it should be easier to increase the proportion of trees with good resistance.

Ascospores have a range of several km (e.g. Aylor, 1999), and the concentration downwind of large sources ('resting' orchards, for example) can be substantial, so the strategic use of resistant varieties should be considered on a landscape scale. The geographic concentration of cider apple production means that there is potential for increasing the resistance level of the apple population as a whole within the growing region.

The use of GM to develop resistant varieties has been discussed as a valuable tool to aid with the general complexities of fruit breeding and could aid with the specific complexities of pyramiding resistance genes, however, currently GM crops are unacceptable to organic growers and many conventional growers in Europe. Commercial growers in Holland are, however, actively collaborating with GM researchers at Wageningen and the public and commercial acceptance of cisgenic and intragenic crops is yet to be fully tested.

Sanitation measures - leaf litter management

The primary source of inoculum for apple scab is ascospores which overwinter in leaf litter. Leaf litter management can also impact pests which overwinter in debris, such as sawfly. Taking scab specifically, any practice that could destroy or remove fallen leaves would reduce the inoculum and therefore scab incidence (Mac an tSaoir *et al*., 2010). Two sanitation measures, shredding the leaf litter and treating leaf litter with urea were evaluated on ascospore dose and build-up of apple scab in the north-eastern United States (Sutton *et al*., 2000). The results showed that an 80-

90% reduction of the risk of scab can be achieved if all of the leaf litter is shredded in November or April. Also, treating leaf litter with urea in November when approximately 95% of the leaves have fallen, or in April before bud break, reduced the ascospore numbers by 50 and 66% respectively. The potential of urea-treated leaf litter for the control of scab has been reported in Kent, England by Burchill (1968) who found that treating Bramley's Seedling trees with a postharvest, pre-leaf fall application of 5% urea reduced scab lesions on blossom-spur leaves the following spring by 59 and 46% respectively. Bassino and Blanc (1975) also reported that in France, applying 5% urea to severely scabbed (>30% foliar scab) Golden Delicious and Starking Delicious trees after harvest but before leaf fall reduced scab the following spring (cited in Sutton *et al*., 2000). Leaf shredding, urea (5%) and inoculation with fungal antagonists (*Microsphaeropsis ochracea*, *Athelia bombacina*) were studied in a Canadian apple orchard as tools to manage apple scab. All four treatments significantly reduced ascospore production with urea being the most efficient (92.1% reduction in ascospore production), followed by leaf shredding (85.2%), *Microsphaeropsis ochracea* (84.8%) and *Athelia bombacina* (80.6%). Also a combination of shredded leaves treated with 5% urea, and shredded leaves treated with *Microsphaeropsis ochracea*, was included in the study later and the greatest reduction in ascospore production was achieved by the combined treatments; shredding + *Microsphaeropsis ochracea* (93.9%) and shredding + urea (90.5%) (Vincent *et al*., 2004).

However, it might be difficult to shred enough leaves to have an impact because of operational difficulties depending on the topography of the orchard and autumn weather conditions (Vincent *et al*., 2004). Sutton *et al*. (2000) for example found that because of the limited offset of the flail mower and spread of the tree canopy, 10-35% of the leaf litter could not be shredded and the risk of scab was only reduced by 50-65%. After shredding it is important to remove leaves from the orchard; this requires additional machinery and could also be achieved by combining leaf shredding with urea or fungal antagonists (MacHardy, 2004) to enhance leaf decomposition (Carisse and Dewdney, 2002). Carisse *et al*. (2000) studied the influence of five potential fungal antagonists (*Microsphaeropsis* sp., *M. arundinis*, *Ophiostoma* sp., *Diplodia* sp., and *Trichoderma* sp.) on ascospore production of scab in comparison with urea and *Athelia bombacina*, a recognized antagonist. All the fungi apart from *Ophiostoma* sp. significantly reduced ascospore production under orchard conditions and the four best treatments were *Microsphaeropsis* sp., urea, *A. bombacina* and *Trichoderma* sp. with overall ascospore inhibition of 90.4, 87.7, 84.2 and

83.7% respectively. The result of the study indicated that *Microsphaeropsis* sp. could reduce overwintering inoculums by at least 75% and therefore help to eliminate sprays early in the season; however, for these findings to be used, they need to be replicated in a commercial orchard. To conclude, leaf shredding could be a valuable and promising component of a sustainable apple orchard, but modification of the practice is required in order to reduce scab risk by more than 80% (Sutton *et al*., 2000).

A two-year experiment was carried out in a commercial organic orchard in France to assess the effect of leaf litter management on scab development. Leaf sweeping from the alleys was combined with ploughing in within the row. In both years, the method reduced the fruit scab incidence by 82.5 and 54.6% respectively and the fruit scab severity by 74.0 and 67.7% respectively, demonstrating the benefit of a complete removal of the leaf litter in reducing leaf and fruit scab development (Gomez *et al*., 2007).

Specific or low impact sprays: particle films, plant extracts and viruses or bacteria

Bostanian and Racette (2008) have studied the use of kaolin particle films in managing arthropod pests of apple in Quebec, Canada. Kaolin is a white, nonabrasive clay (Bostanian and Racette, 2008; Markó *et al*., 2008), which acts as a pest management tool through repelling, disrupting feeding and oviposition, decreasing longevity and increasing mortality of arthropod pests on treated foliage (Bostanian and Racette, 2008). Initially, kaolin was used in a hydrophobic form, but later on in 2001 it was replaced by a hydrophilic formulation under the commercial name Surround WP (Markó *et al*., 2008). Even though several studies demonstrate the potential of kaolin particle films as a pest management tool for apple orchards (e.g. Unruh *et al*., 2000), this technology has the disadvantage that it is species specific. In the study by Bostanian and Racette (2008) for example, kaolin was effective against European apple sawfly (*Hoplocampa testidunea* Klug), white apple leafhopper (*Typhlocyba pomaria* McAtee), apple red bug (*Lugidea mendax* Reuter), pear plant bug (*Lygocoris communis* Knight), and the apple rust mite (*Aculus schlechtendali* Nalepa). However, it was not effective against apple maggot (*Rhagoletis pomonella* Walsh), codling moth (*Cydia pomonella* L.) and tarnished plant bug (*Lygus lineonaris* Palisot de Beauvois). Delate and Friedrich (2004) in contrast found that kaolin was effective against codling moth in organic apple orchards in Iowa. The same was the case in the Netherlands where the use of kaolin resulted in reduced codling moth fruit damage (Markó *et al*., 2008). In the same study, there was an effect of kaolin on apple sawfly infestation on cultivar James Grieve but not on Golden Delicious. In terms of the rosy apple aphid infestation was increased under the kaolin treatment and similarly the woolly apple aphid infestation was promoted. The advantages of kaolin are its very low mammalian toxicity and the low risk for the environment (Markó *et al*., 2008). One problem associated with its use is the dust residue left on the fruit; however, this is not a problem for processing fruit where the cosmetic appearance is not important (Dufour, 2001).

An alternative method for apple scab control is the use of plant extracts. This was first reported by Gilliver (1947). Plant extracts from 1915 different species were tested for their effect on germination of conidia of *Venturia inaequalis*. 440 of the extracts tested had an inhibitory effect with extracts of common ivy (*Hedera helix* L.) being the most effective. However, there is no reason to suppose bioactive plant extracts will not have ecological side-effects in the same way as single chemical species derived from or analogous to naturally occurring compounds.

Vries *et al*. (2005) studied the effect of *Galenia africana* (a low growing herb native to southern Africa) extracts on apple scab and achieved significant control of the disease on leaves and fruit in comparison with a water control, and similar or better control in comparison with a commercial fungicide (0.15% Mancozeb). Since these extracts have broad spectrum activity, the scope for unexpected ecological side effects is considerable; the problem, of course, is that such side effects are likely to appear only with widespread use. Again diversity of practice is advantageous in minimising risk.

In another experiment in the Czech Republic, the extract from the plant *Quassia amara* L. was tested for the control of the apple sawfly (*Hoplocampa testidunea* Klug) in organic apple orchards (Psota *et al*., 2010). The extract contained the oxygenated triterpenes quassin and neoquassin and it was statistically significant in reducing the fruitlets infestation. Dosages of 3 or 4.5 kg of quassia wood chips/ha gave a reduction in fruitlets infestation from 50-85% depending on the year and location. Higher dosages or two successive sprays were not more efficient. Despite the efficacy of the extract against the apple sawfly, the authors recommend the test of the product in a bigger size orchard.

Landolt *et al*., (1999) investigated the effect of essential oils of 27 plant species against codling moth larvae, oil of lavender (*Lavandula officinalis* L.) was most effective in repelling larvae, and oils of several other species also were effective. It is possible that sprays of this nature may be effective in preventing the codling moth neonate larvae from finding a suitable apple fruit to bore into.

Another study was conducted to evaluate the effect of plant extracts on the germination of the apple scab conidia (Maxim *et al*., 2005). The plant species tested were *Armoracia rusticana*, *Daucus carota*, *Urtica dioica*, *Primula officinalis*, *Juglas regia*, *Cannabis sativa*, and *Equisetum arvense*. The results showed that the plant extracts had an inhibitory effect on the conidia germination.

In the US antibiotic sprays have been widely used against fireblight but this is unacceptable in the UK, where copper-containing compounds would be the only practical chemical spray. In practice, fireblight has proved less of a problem than initially feared, provided infection is kept out of any susceptible plants in hedges of or close to orchards. Numerous studies of the use of competitive bacteria or phage infection (Thomson, 2000; Vanneste, 2011) have been made.

Some of these alternative sprays have quite high environmental costs elsewhere and should not be regarded as sustainable. This is especially true for kaolin, because the application rates are high and the quarrying and transport have considerable environmental impact (Peck 2010).

Alma *et al*. (2001) described a technique to control codling moth under the name ‘attract and kill’ (AK). This technique uses a formulation of sex pheromone Codlemone (0.16%) and pesticide Permethrin (6%) with knock-down action by contact; it is applied in the form of drops on trunks or woody branches of apple trees. The male population of the codling moth is then attracted by the pheromone and dies or is disoriented in the attempt to find the females and therefore mating is disrupted. The authors of the study conducted three years experiments using the AK technique in apple orchards in Italy which were consistent in their results with the damage at harvest being lower than 1%, similar to the conventionally treated orchards. Pheromonal control of codling moth was also tested in Romania by an ‘attract and kill’ formulation made for experimental purposes (Somsai *et al*., 2010). The product contained the codling moth pheromone (E, E-8, 10 dodecadien-1-ol) and the insecticide cyfluthrin. Field trials showed that the ‘attract and kill’ method may be a good tool for the control of codling moth in IPM of fruit growing.

The use of granulosis virus against codling moth, *Steinernema* nematodes and mating disruption or mating attractants coupled with granulosis virus (Cross *et al*., 2005) seem likely to provide control if needed in cider orchards (Dapena *et al*., 2005) and are of intrinsically low environmental impact. However, they are not necessarily sustainable if over-used. In particular, the granulosis virus or nematodes should be regarded as a minor component of the management toolkit in a sustainable system, or resistance is very likely to develop: it has already occurred with granulosis virus in organic systems (Sauphanor, 2006). Microbial control discussed by Lacey and Shapiro-Ilan (2008), and they usefully discuss its role in orchard IPM. For codling moth the granulosis virus CpGV is the most effective microbe against it, but exposed larvae live long enough after infection to damage fruit, with larvae usually dying as early instars within the skin of the fruit. In itself this would not be a problem with cider production, but the dmage could increase levels of brown rot. In addition, virus must be reapplied every 1 to 2 weeks due to UV degradation, and resistance to it identified in Germany and France. It could be integrated with other control measures to reduce possibility of resistance developing.

The pheromone/sterile based (Vreysen *et al*., 2010) systems of insect management discussed above for codling moth could have potential for sawfly, but the research costs are probably too high for a minor pest. There has been preliminary work on the use of soil fungi to attack the over-wintering stages of sawfly (Jaworska, 1979), and this could be worth following up in the context of alternative alley management methods.

Mating disruption (MD) has been used on 77,000 ha of apples/pears in N. America, 38,000 ha in Europe, 19,000 ha in S. Africa, 28,000 ha rest of world, using codlemone, main compound of codling moth sex pheromone, made synthetically. Integration of synergistic chemicals into the mix can improve attraction, and effect can be synergised by plant volatiles as well the main limiting factor is density; mating disruption is hard to achieve if the density is more than 1000 overwintering larvae per ha, but can be combined with insecticide/granulovirus early in season (Witzgall, *et al*., 2008).

Augmenting and maintaining reservoirs of natural enemies

The importance of natural enemies is acknowledged in current conventional apple production through the avoidance of insecticides which will kill predatory mites; this has more or less removed the need for active mite control which was a major issue in the 1960s and 1970s. Specialist parasitoids and mycoparasites have the paradoxical property of requiring a moderate permanent presence of their host. For dessert apple production, where even cosmetic blemish is important, this may make it impractical to aim at using unmanaged natural enemies to control pests, but the somewhat relaxed quality criteria for cider production may allow new options. The open nature of orchards and the relatively small size of the sector make development of augmentative biocontrol (where control is achieved by release of captive-bred natural enemies) with insects intrinsically difficult because of dispersal, and therefore unlikely to be economic.

The study of natural enemies is most advanced in the insect field. Numerous lines of passive management have been suggested in the literature which are compatible with enhanced biodiversity and cheap to implement. Promising examples are fewer for diseases. This is partly because predation and disease are easier to study in arthropods than in fungi, but possibly also because of intrinsic differences in ecology.

Codling moth has largely been discussed above. It has parasitoids, one at least of which is being targeted as classical biocontrol agents; the larval ectoparasitoid *Mastrus ridibundus* (Gravenhorst), a natural enemy of codling moth was introduced from the USA into South Africa but little information is available related to its biology and ecology and this is a knowledge gap for the design of an efficient strategy (Devotto *et al*., 2010). The parasitoid is believed to be a strict specialist, in which case the low populations of codling moth present in cider orchards may already contribute to maintaining a population of parasitoids which stabilises the population. However, there is some evidence that other parasitoids may be slightly more generalist, in which case, as with rosy apple aphid, greater biodiversity in and around cider orchards would lead to better control. However, the plant-host specificity shown by almost all parasitoids suggests that biodiversity in itself is not helpful: specific plant hosts are needed.

For rosy apple aphid, probably the most important pest of cider apples, use of rowan (*Sorbus aucuparia*) and elder (*Sambucus nigra*), a minor but profitable fruit juice/flower crop in hedging has been shown to reduce aphid infestation by increasing populations of predatory syrphids (Diptera: Syrphidae) and coccinellids (Coleoptera: Coccinellidae) (Bribosia *et al*., 2005a, b). In the Belgian study by Bribosia *et al*. (2005a) a system involving *S. aucuparia* was developed to provide in-field production of parasitoids of the rosy apple aphid in apple orchards. This was achieved by artificially providing *Dysaphis sorbi* Kaltenbach, an aphid that constitutes an alternative host of the parasitic wasp *Ephedrus persicae* Froggatt, which attacks the rosy apple aphid. The provision of the alternative hosts was achieved by planting rowan trees (*S. aucuparia* L.) artificially infested with *D. sorbi* eggs in the orchard. This technique suggests a possibility for *E. percicae* to serve as a reservoir of biocontrol agents against rosy apple aphid infestations. Common elder (*S. nigra* L.) was also tested for the control of the rosy apple aphid (Bribosia *et al*., 2005b). Elder shrubs host the aphid *Aphis sambuci* L., which can maintain aphidophagous syrphids; the plants were therefore artificially infested with *Aphis sambuci* and planted as bordering hedgerow in order to serve as a reservoir for syrphids. Syrphids are generally flower-visiting insects which require pollen for egg maturation. When tested for the pollen source they were visiting, it was found that even though there were other flowering species around, the pollen excreted by the syrphids was coming from *Lamium purpureum* L. and apple. The results indicate that the use of common elder to promote aphidophagous syrphids in apple orchards is a promising tool for the control of the rosy apple aphid and it does not require pollen or nectar from other producing plants apart from the apple trees.

Exclusion of ants by banding the trunks of trees has been shown to reduce rosy apple aphid populations in several studies (Stewart-Jones *et al*., 2008; Bird *et al*., 2004); this is consistent with other studies in natural systems. Conversely, use of kaolin as a blanket (albeit passive) insecticide has increased aphid populations by reducing predation (Markó *et al*., 2008). The presence of *Plantago* in the alley cover appears to have no effect on rosy apple aphid abundance, though as an evergreen it might be expected to harbour a population of both aphid and its predators and parasitoids throughout the year, which might be beneficial or damaging. Other aphids are also known to be regulated by natural enemies, and inundative releases of ladybirds have reportedly given success (Wyss *et al*., 1999); they are unlikely to be economic in cider orchards.

Venturia inaequalis, scab, has to compete with decomposing micro-organisms on fallen leaves to complete the life cycle and release ascospores after the winter. Natural enemies therefore include saprophytes such as *Chaetomium globosum* (an antibiotic producer, unsuitable for augmentation but very effective) and *Athelia bombacina* (proposed for commercialisation but not yet available), as well as earthworms. The prospects for biocontrol on leaf or fruit surfaces are poor: coverage would need to be excellent unless the organism secreted a relatively potent antifungal, in which case there would be serious safety issues.

Powdery mildew is subject to attack by a range of mycoparasitic fungi, including the specialist *Ampelomyces quisqualis*. These are largely ineffective on susceptible varieties of apple, for two reasons. First, they increase in population behind the pathogen, rather than having a reservoir on other hosts which could check the pathogen early; host specificity in *A. quisqualis* is in any case barely studied. Second, overwintering inoculum is substantial in the inaccessible inter-scale spaces of the buds. However, pruning and use of reasonably resistant cultivars means that damage by powdery mildew should not be significant in apple orchards.

Apple replant disease is unlikely to be a serious issue in extensive orchard systems because of their long life-times, but can be a significant problem in intensive systems in which trees may be replaced more frequently to alter the design or introduce new varieties or rootstocks. The causal organisms are unknown, but the problem occurs in many rosaceous plants and has been observed in *Prunus* spp. in natural forests of unmanaged species composition in the eastern US (Packer and Clay 2004). It is discussed here because the gradual buildup suggests development of a mildly pathogenic community around the roots of established apple trees, and incorporation of organisms antagonistic to the pathogenic components of these communities is the only plausible method of control. Between crops, at present, only complete soil sterilants offer an option to manage the problem. These have environmental disadvantages and leave the soil vulnerable to invasion by other undesirable organisms. Research is needed, but is unlikely to have a rapid payoff because of the slowly developing and vague nature of the problem. Developments in metagenomics offer hope that tools to solve the problem may now be available.

1.7 Integrated Pest Management

Explicit, IT based advisory systems

The use of fungicide and insecticide has led to a huge investment in research on good timing in an attempt to minimise use. This is assimilated to growers through the experience of advisors and summary printed advice, which is not well-adapted to real-time changes in conditions. There has therefore been substantial investment also in algorithm-based advisory systems linked to understanding of the dynamics of pests or diseases in relation to weather.

ADEM™

The current unsupervised practice in the UK for the control of scab (*Venturia inaequalis*) and powdery mildew (*Podosphaera leucotricha*) consists of routine application of fungicides at 7-14 day intervals from bud burst to harvest. Such routine programmes are simple, effective and reliable; however, public concern about the possible side effects of pesticides on human health and the environment has led to the exploration of control methods which have the potential to optimize the use of fungicides. One example is the disease-warning systems, ADEM™ (Apple Diseases East Malling), a system developed by Horticulture Research International, East Malling, UK. It is a PC-based system using epidemiological models that relate the development of the diseases to biotic and abiotic factors and warns of the risk of scab, mildew, *Nectria* fruit rot and canker (*Nectria galligena*) and fireblight (*Erwinia amylovora*) so that fungicide applications can be curative rather than routine (Berrie and Xu, 2003) and unnecessary sprays can be avoided (Berrie, 1997). In the case of scab, ADEM™ finds when infection is likely to occur for conidia and ascospores and then forecasts leaf scab incidence, taking into consideration the inoculum quantity in the orchard and the cultivar susceptibility, while the mildew model forecasts the likelihood of epidemic of secondary mildew (Berrie, 1997). In trials carried out at East Malling comparing control of scab under sprays routinely applied from bud burst to harvest at 10-day intervals) or at key-stages (bud burst, petal fall, and according to warnings by ADEM at other times), it was found that satisfactory control was achieved by the key-stage system with a 20% reduction in fungicide. This resulted in £50/ha savings on fungicides. The same was the case with mildew, where control using ADEM warnings was achieved with 50% reduction in fungicide use. This indicates the potential of disease-warning systems (ADEM^{TM}) for scab and mildew control with reduced fungicide use (Berrie, 1997).

In recent years electronic warning equipment has gained acceptance for the control of apple scab even though they have long been in use, since Mills and Laplante (1954) defined the weather conditions that favour the apple scab. Such systems use weather data to time fungicide applications only when they are needed (Beresford, 2010). In field trials in Lithuania the scab warning system METOS^{R}-D was used to detect infection periods and forecast disease intensity (light, moderate, severe). This integrated disease management system was compared with conventional disease management (nine sprays per season) and it was found that it gave a 30-44% reduction in spray applications depending on the cultivar susceptibility; however, the two strategies did not differ in terms of scab incidence (Raudonis, 2002). Although similar systems have been available in the UK, they have not been popular with growers, who prefer to modulate the advice based on integrating weather data with knowledge of the infection status of the crop and the growth stage, as allowed by ADEM, for example.

SOPRA

In Swiss apple orchards a phenology-model named SOPRA has been developed as a forecasting tool for insect pests (rosy apple aphid, apple sawfly, smaller fruit tortrix). The aim of the model is to optimize the timing of monitoring, management and control measures. The model used the relationships between temperature and developmental stage, which were established under controlled conditions. In order to validate the model its predictions were compared with field observations from several years in terms of hatching of winter eggs for the rosy apple aphid, and adult emergence for the apple sawfly and the smaller fruit tortrix. The results are widely disseminated in Switzerland and southern Germany as a tool with which to synchronise sprays with peak vulnerabilities in the pest populations. (Graf *et al*., 2002; Samietz, 2008). Development work would be needed to test the models and the value of using them under UK conditions, now or in the future.

Conclusions

The main pests and diseases in cider orchards are similar to those in dessert and culinary apples. But the emphasis on management differs because drivers of orchard structure differ. In addition to chemical pest and disease control other alternative approaches also exist. These include the use of ground cover plants, resistant varieties, sanitation measures (leaf litter management), use of particle films, plant extracts, viruses, bacteria, reservoirs of natural enemies, and IT based advisory systems such as *ADEM™* and *SOPRA. However, for this potential to be realized the most likely options need to be tested in selected orcharding systems (intensive or extensive). This is discussed further in Part 2 and 3.*

Part 2: Towards greater sustainability in UK cider orcharding

In this section we provide a synthesis of the preceding information, making specific suggestions for the future and identifying potential problems.

2.1 The tree

The future cider apple tree will need to be adapted to the predicted UK climate. Climate predictions vary but the generally agreed features are: milder, wetter winters, warmer, drier summers with associated more extreme weather events (for example, heat waves, heavy rainfall and high winds, increased likelihood of water deficits in all but the wettest areas and most water retentive soils). Summer rainfall in the South East could decrease by 30% by 2050. By 2020 and 2050, the mean temperature across the UK is likely to rise up by up to 1.5 and 2.5 ^{o}C respectively. By 2080, the mean temperature across the UK is likely to rise by 2 and 3.5^{o}C according to the low and high emissions scenario respectively (see www.apis.ac.uk). The impact of climate change on orchard crops is likely to be significant as crops planted now might be expected to remain in the ground for twenty years or more, by which time the orchard will be experiencing significantly different climatic conditions than at present. Predicted climate change is likely to result in reduced winter chilling, altered flowering periods (and activities of pollinators), high temperature and drought stress at times during the fruit swelling period (June - September), and altered harvest dates.

New varieties will be needed which are better adapted to future climates. It would be logical to anticipate reduced chilling by characterizing the chilling requirements of existing cider apple varieties, for instance, accessions at the National Fruit Collections (Appendix 3) and elsewhere and by generating new selections from crosses between low chill varieties and valued cider varieties. Varieties adapted to warmer climates, such as in northern Spain, could also be collected and tested for future UK production, although such varieties could be more susceptible to frost damage. It may also be possible to devise cultural treatments to extend the period over which chilling is accumulated (e.g. by encouraging earlier leaf fall), and thereby satisfy the chill requirement of existing cultivars during milder winters; but the associated effects of such treatments would need to be carefully studied.

Future orchards are likely to rely more heavily on drip irrigation than at present and similarly, resilience to increased soil water deficit should also be a selection criterion in future breeding programmes, especially for rootstocks. Such drip systems will need to be combined with advanced soil moisture monitoring systems to enable irrigation to operate with a high degree of efficiency. However, these systems could also be combined with fertigation so that nutrients can be supplied as the season progresses and in relation to crop status (monitored, for example, using SPAD[2] meters). These systems are already being used in the UK in the soft fruit industry, but have yet to be used widely in top fruit crops, although this approach has been used commercially on intensive orchards in Canada (see Neilsen *et al*., 1995).

To avoid potentially negative effects on fruit set of pollinator disruption, the self-fertility of some cider apple varieties could be exploited. This character needs to be better studied and understood – what are its causes and how consistent is it (e.g. year-on-year). The apetalous trait could also be used in breeding to enhance parthenocarpy in a similar way to that discussed for dessert apples, but possible negative effects on yield would need to be monitored. Current understanding of the genetic basis behind parthenocarpic fruit development means a molecular breeding approach to this character is potentially possible.

At the whole tree level a key problem trait for cider apples is biennial (or irregular) bearing. This topic is being addressed at a genetic level in dessert apples as previously discussed, but its complexity means that progress will come through long-term investment, leading to the inclusion of cider accessions in these existing programmes. Alternative approaches might be either development of gibberellic acid-based treatments through carefully managed spray applications, or development of economic systems in which irregular bearing is less critical.

[2] The SPAD meter is a leaf meter (manufactured by Minolta) which provides an instantaneous assessment of leaf chlorophyll and is commonly used to provide a non-destructive assessment of plant nitrogen status as an alternative to leaf sampling and laboratory extraction and spectrophotometric analysis.

2.2 The system

'Intensive': tree density of 400-600/ha

There is little doubt that, as with dessert apple orchards, increased productivity can be achieved through maximizing light interception through the adoption of more intensive, high density planting systems. Although there are few published data for cider apples, these relatively intensive modern 'bush' tree plantations come into cropping earlier and are therefore higher yielding during the early life of the orchard. They are typically managed as central-leader trees with spiral pruning to remove large branches; mature trees can be 1.8-4.6m tall in rows 4.5m apart. Light interception is likely to be better relative to more closely planted trees in wide rows, but such data are lacking and physiological analysis is needed to define systems that maximize light interception. It seems likely that further gains in productivity could be achieved, and the potential of Y-shaped plantings should be explored as discussed in Part 1.

Overall this approach is focused on optimizing yield through maximized tree productivity. The downside is greater sensitivity to pests and diseases and to climatic excursions and reduced opportunities for increasing sustainability. The sustainability agenda could nevertheless, be addressed by minimizing waste (see below) and pesticide application; if Y-shaped planting was employed there would be probable benefits to sward management due to between-row shading. A fully Y-shaped planting might prevent access to much conventional machinery; but specialized low machinery could "brush" the apples off the trees. The system might also require zero spray methods of pest and weed control because conventional blast assisted or row straddling sprayers could not get in if the canopy was effectively closed. Because the orchard area itself is focused on crop production, a set-aside area next to (or surrounding) it is likely to be the best way to provide an environment conducive to beneficial insects. As discussed, hedges of rowan and elder have been found to reduce aphid infestation by increasing populations of natural predators.

'Extensive': tree density of 100-150/ha

Traditionally cider apple trees were widely planted as standards, and the orchard had a dual function of livestock and cider production. This approach is still in use, where grants for establishment and the wider context of the farm make it desirable. Sustainability against this background involves management of sward composition and intercropping, with both additional crop and beneficial insects and biodiversity in mind; and optimized management of waste prunings (see below). Here, the vision is for a more extensive, low density and low maintenance orchard system, where a managed cover crop is grown that provides pollen and a habitat for pollinating and beneficial insects. A number of potential cover crop species could have roles in such a biologically rich growing system but it is clear that such a system would need careful management to ensure the continuation of a diverse habitat which also does not compete significantly with the trees. Apple trees could be interplanted with earlier-flowering nectar rich tree species, in the way peach has been used in the US, to increase the abundance of beneficial insects. Soil structure can be enhanced through the addition of composts and biochar which could lead to more sustainable soil nutrition and enhanced biodiversity of arthropod predators and beneficial fungi associated with the breakdown of organic matter in composts.

Under extensive orchard systems vegetated alleyways are likely to remain the preferred management option based on sown grass or legume mixtures. The function of these alleyways is diverse, serving to reduce soil erosion and pesticide run-off on steep gradients, suppress weeds, provide accessibility and reduced soil compaction, and supply pollen and nectar and refuge for beneficial invertebrates. The choice of ground cover species will be influenced by climatic conditions and edaphic factors such as pH. A range of species is available and offer a variety of opportunitites: *Trifolium fragiferum* is tolerant of waterlogging, whereas *Trifolium incarnatum* is drought tolerant and *Melilotus alba* intolerant of acid soils as is *Medicago sativa*. Although *Trifolium repens* is not unduly sensitive to acid soils its optimal pH is between 6-7. *M. alba* and *T. incarnatum* are annual species that would necessitate re-seeding. Nonetheless, care would have to be taken to ensure that adequate weed suppression was not compromised by excessive competitiveness with the crop (the rationale for the adoption of herbicide strips was to reduce such competitive effects, particularly for soil moisture). Also choice of herbage grass for inclusion in the legume mixture would be influenced by location; *Phleum pratense* would be appropriate for wetter soils in the west whereas *Dactylis glomerata* would be more suited to the drier eastern counties. *Festuca pratensis* is less competitive than *Lolium perenne* but is less persistent. *Festuca rubra* has attractiveness in that it is durable and yet not excessively competitive, albeit not particularly productive.

Traditionally the orchard floor vegetation was grazed by livestock, but the reduced height of modern cider apple varieties would preclude the use of cattle. Inclusion of *Lotus corniculatus* as a ground cover would not be advisable under such conditions because of the presence of glycosides affecting sheep oestrogens. Recent concerns regarding the potential risk of *Escherichia coli* from faecal contamination of the harvested crop by sheep have necessitated a voluntary withholding period of 56 days prior to harvest. Whether sheep grazing remains a viable option is dependent on the economics of sheep production. Irrespective of this, the vegetated covers will need to be periodically mown and this could have implications for maintenance of predatory arthropods. Removal of vegetation as conserved forage e.g. hay or silage would also have a bearing on the choice of grass or grass legume mixture, but would be dependent on alley width and access to machinery as would the possibility of intercropping combinable crops including wildflower mixtures, wildbird seed and game cover crops.

Alternatives to traditional grass alleys are various mat forming perennials either for weed suppression or as source of pollen and nectar for beneficial predatory arthropods. However, annual species too have considerable merit as exemplified by *Phacelia tanacetifolia* and *Melilotus officinalis*. Similarly the presence of vegetation within the tree row has been shown to be superior to either bare ground or mulches in terms of predatory carabid beetles. However, species of erect habit such as *Centaurea nigra* may have greater value than prostrate species such as *Trifolium repens*. Annual members of the Asteraceae such as *Anthemis cotula* have been demonstrated to be effective attractants of beneficial arthropods within orchards, although the cost of sowing wildflower mixtures is likely to be prohibitive unless feasible within agri-environment scheme options. Likewise, the inclusion of other tree/shrub species either as alternate rows or within row of differing canopy characteristics could enhance both insectivorous birds and beneficial arthropods as would the provision of shelter belts.

Ultimately, the choice of vegetation either within the tree row or the grass alley will be dependent on its primary purpose. This should be as a component of an integrated approach to pest and disease management, to encourage beneficial predators and achieve acceptable weed suppression. Further research is required to identify which species are optimal as nectar and pollen sources for foraging insects (including pollinating species such as bees and beneficial predators) in order that their populations are maintained outside periods of pest activity; plant species which provide optimal refuge for ground dwelling invertebrates would also need to be identified. Furthermore, the impact of timing and frequency of defoliation on these populations needs to be ascertained, as do the implications for pest dispersal. Recommendations would need to be tailored to individual parts of the country, particularly with regard to mitigation of the effects of climate change.

There are also more subtle aspects which should be considered: for example, it has been discussed that larger trees from traditional orchards may produce fruit with lower nitrogen content and higher polyphenolic levels. This effect can be attributed to the high nutrient status (and consequent higher yields) of intensively cultivated trees; whatever its cause, it may be significant where polyphenolics are valued because of perceived health-benefits. Evidence presented earlier showed that, under soil fertility conditions required to support high productivity, such as those within intensive orchard systems, it is difficult to manage sward conditions that include legume species either alone or in combination with grass species, since grass species tend to outcompete legumes unless managed with herbicides or growth regulators. In contrast, more extensive, low density growing systems may achieve low enough soil fertility to enable legume ground cover mixtures to flourish; but careful management of such systems would be required as available evidence suggests that legumes, such as clover, can adversely compete with orchard trees. Nevertheless, an extensive low density, low nutrient status system could be devised which enables fruit to be produced with higher health benefits against a background of a biologically diverse groundcover system capable of fixing nitrogen and supporting a diverse fauna. Such a system, with mature trees of potentially long life-time and long time to full cropping, is necessarily slower to respond to climatic and economic changes, though it may be intrinsically more resilient because of the nutrient reserves and larger rooting zone of the trees.

The two systems described above are shown in Figure 12.

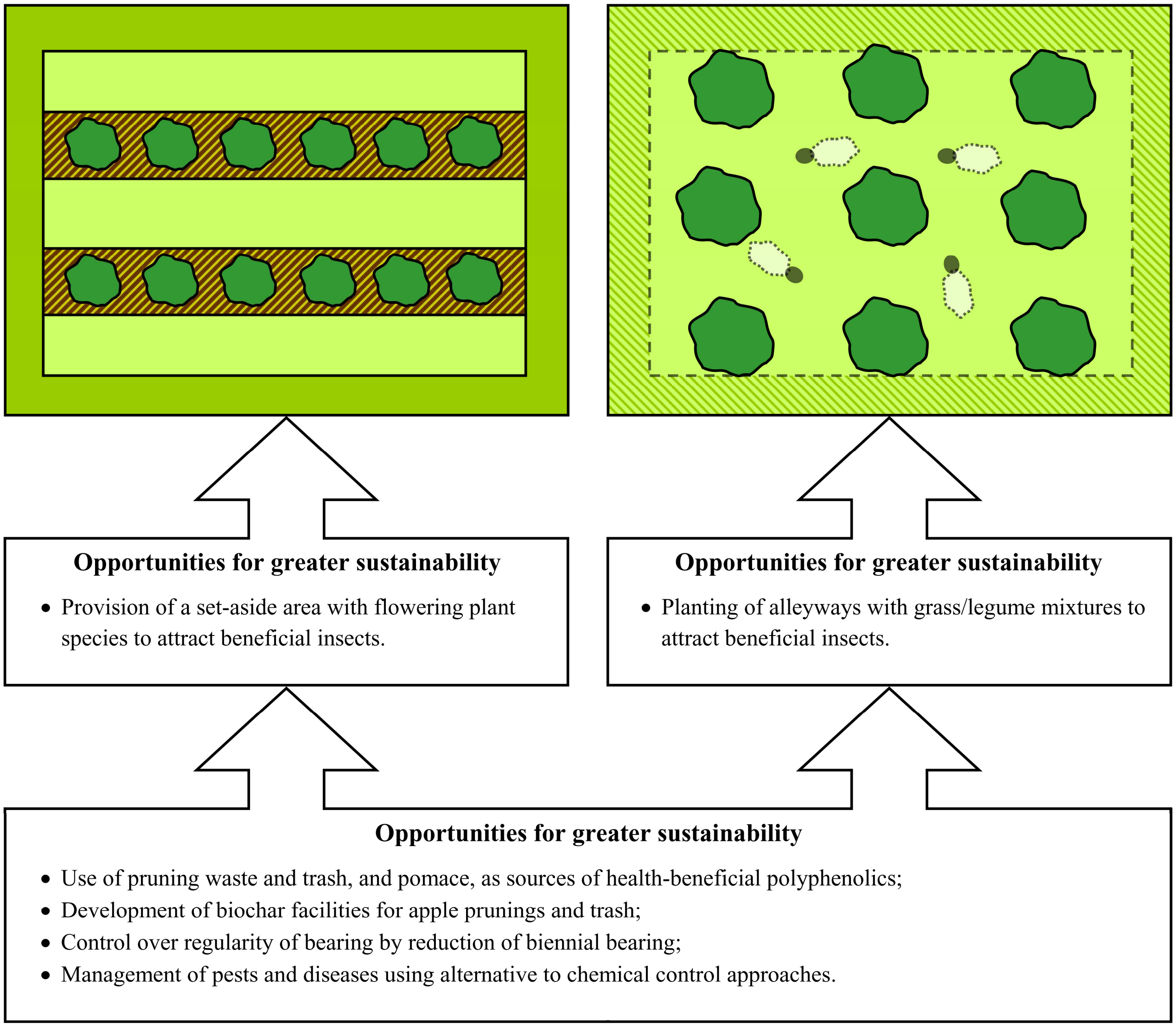


Fig. 12: The intensive system (on the left) has tree-row strips (brown), grass alleys (light green), and a set-aside area of flowering plants (dark green). The extensive system (on the right) has grass alleys (light green) and a set-aside area of flowering plants (vertical hatching) if grazed.

'Mixed farm': smaller blocks of cider apple trees intercropped

This is essentially a whole farm approach and here sustainability would be addressed in the broadest sense, including local livelihoods. Cider apple production for the grower would be a relatively small contribution to revenue, and the production system would involve small to very small individual plantings and minimal investment in highly specialized equipment unless very cheap. Cider production itself would be either a local activity or more likely involve aggregation of output from numbers of growers, either via a co-operative or directly by the cider producer. The system would be seen as one which was part of a landscape providing employment, biodiversity and food as joint goals.

This is a farming rather than a growing system, which could take and/or modify its production method from the intensive or the extensive systems. Such a system might involve single rows or blocks of smaller trees which would integrate more easily with neighbouring crops in stockless systems or full size standards as in a silvi-pastoral system. Because of the diversity of outputs envisaged from a single economic unit, biennial bearing need not be an over-whelming problem; however, good pest and disease resistance would be important, and this and resilience and biodiversity demand the growth of several varieties on each holding. This would be constrained by the need for matching juice characters as well as good disease resistance. Research could involve wider phenotypic characterization of less widely used varieties; better understanding of the regulation of pests and diseases at different scales; and socio-economic modeling of outputs. Martin Wolfe's experiences at his experimental farm in Suffolk might be an informative start to study of this model (http://www.wakelyns.co.uk). A major constraint to such idealized mixed farming systems is their limited economic viability.

2.3 Pest and disease control within these systems

Minimal or zero agrochemical residues in the juice will remain a priority; all integrated management systems work better, the better the intrinsic resistance of the host. Also, the wider the genetic basis of a crop, the less vulnerable it is, in aggregate, to invasion by novel or newly adapted pests or diseases. Therefore, regardless of growing system, deployment and acceptability testing of a range of varieties should be a priority, and research into socio-economic/purchasing factors which might mitigate what will otherwise be the drive to a narrow range of physiologically superior varieties should be planned. Developments in IT and product tracking, such as RF tags, should make handling and aggregation of diverse product easier.

The extensive and mixed models provide smaller areas of favourable habitat, greater emigration of pests and more scope for natural enemy regulation (Prokopy, 1991), but are harder to apply specific biocontrols in, for the same reasons. Insofar as they employ more open canopies, they will also be less prone to most fungal diseases because of reduced humidity and more rapid drying as well as greater distance from less intense inoculum sources. Some specific problems caused by pests with a wide host range, such as fireblight, could be worse in a more diverse system. However, as discussed, deployment of competitive biocontrol bacteria or phage would be possible in such a system, were fireblight to emerge as a more serious problem in apple as climate changes phenology.

The intensive model allows optimized spray and litter management systems and deployment of intricate biological/chemical controls such as Exosept or mass release. Cider production by itself is unlikely to justify the development of novel pest or disease management systems: realistically, development and commercialization of a biological control for a single target host requires a high value industry or world-wide applicability. Use of low-impact chemicals (potassium bicarbonate, detergent solutions) is likely to be pioneered by the dessert apple industry with translational research needed to modify systems for the requirements of cider production. All systems need monitoring and response to developing problems, but – beyond ensuring that short-term considerations do not lead to complete loss of specialists with knowledge of perhaps obscure organisms or disorders – it is by definition impossible to say what will become the major problems in a partially understood system.

2.4 The products

The following areas offer opportunities for increased sustainability in cider apple production.

Prunings and trash

Quantitative data on the production of prunings (and leaf litter) per ha from cider apples (extensive and intensive) would help to decide the best use of prunings and trash. Possibilities include extraction of phenolics (it would be valuable to establish the potential market for such products) and biochar (where it would be valuable to establish how technology can be accessed/developed; whether this would be done in situ or in a central facility). Whilst it may be possible to generate energy from prunings and trash, the alternative of using these wastes for biochar production may be a more sustainable option for these materials in which the biochar produced could be incorporated into orchard soils. Because of its long-term persistence once incorporated into soil, and its equivalent beneficial effects to increasing soil organic matter content, this may lead to more durable effects than achieved conventionally by adding composted wastes to soil to counter, for example, the negative effects of the use of herbicide strips on soil organic matter content.

Pomace, juice and cider

These could be made maximally health-beneficial through retention (or addition of wood/pomace-extracted) polyphenols. But data on commercial priorities are needed.

Robotic technology

Great strides have been made in the fields of robotics which could have applications in cider orchards of the future. Such technologies could revolutionize the development of planting systems that optimize light interception. The vision here would be for orchard systems which establish quickly, come into bearing early, optimize light interception and reduce alleyways. The need for large alleyways to allow access for machinery could be minimized by the use of a new generation of small, self-navigating, robotic machinery which would largely operate below closed canopies, carrying out maintenance operations such as routine application of pesticides from below rather than from the side or above. The technology already appears to exist that enables more intelligent machinery to use image analysis and canopy light reflectance to determine the need for particular actions on a tree to tree basis. Robotic harvesting may offer dramatic solutions in future intensive orchard systems, particularly in cider orchards where fruit handling is less of a priority. However, this may need to be accompanied by a search for the best tree architecture more suitable for mechanical harvesting.

2.5 Research into practice

To obtain the data to allow the above visions to be further assessed and realized, small replicated orchards need to be established where high quality research is required to evaluate research ideas. In addition, demonstration areas need to be established in which research results can be brought together with best current practice to create concept orchards which can be viewed and monitored regularly by the industry. This needs to be carried out where the main industry activity is taking place i.e. in the West Country, and may be best achieved through a partnership between industry and private farm advisory services. The latter have the expertise to manage demonstration orchards and the commercial incentive to do this well and cost effectively since it will support their advisory activities. This view of research into practice is summarized in Figure 13.

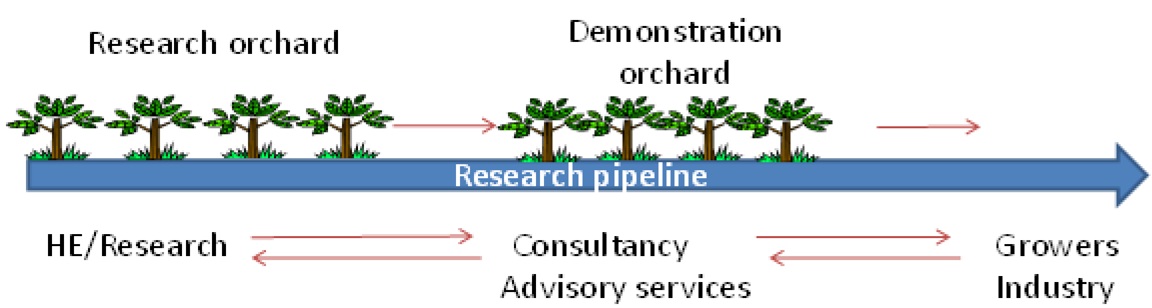


Fig. 13: Pipeline for research into practice

Part 3: Conclusions and proposals for implementation

- Two main options for cider orchards exist:
  1) The focus of the first is intensification. The system requires smaller trees, planted in arrangements which allow maximum light interception, maintenance and harvesting of the crop with minimum labour input. Possible opportunities for further development include the use of small, self-navigating robotic machinery, which would largely operate below closed canopies and carry out maintenance applications (e.g. routine application of pesticides) and harvesting. The use of such technology requires a search for the best tree architecture for mechanical harvesting. Here, ecosystem sustainability may be best addressed through a set-aside area next to (or surrounding) the orchard, and designed to maximize beneficial insects.
  2) The second option involves a more extensive system where ecosystem services are provided over the whole orchard. This is a low maintenance system with a cover crop to provide pollen and a habitat for pollinating and beneficial insects. Intercropping and grazing are options for this system.
- Trials need to be carried out in both systems for the best sward composition (see Part 1 and 2 for further details on plant species).
- Climate change scenarios predict warmer, drier summers and an increased likelihood of water deficits. One element, key to the ability of apple varieties to mitigate the effects of climate change may be the development of rootstocks able to cope with altered availability of water. Current work at East Malling Research is focussing on the development of genomic tools for the pre-selection of water-use efficiency in rootstocks. Reduced winter chilling is also predicted and therefore generating new selections from crosses between low chill varieties and valued cider varieties is a logical criterion for future breeding programmes.
- Self-pollination can be variable from year to year for reasons that are not understood. Pollinizers are therefore always needed, even with varieties which are considered self-fertile. The pollination requirements of cider apple varieties need to be studied carefully and systematically over several years in order to understand self-fertility and how it is controlled. In the long term its genetic basis should be established. Other areas for careful

and systematic study include reduction of biennial bearing and enhanced polyphenol content of fruit.

- In terms of the traits required for addressing the above challenges of climate change mitigation as well as the possibilities of developing more intensive systems it would be an important step to further evaluate the available cider varieties, within the UK and beyond with these specific questions in mind. This would allow both the identification of varieties able to help address the challenges in the interim and also allow the identification of varieties to include in any further breeding work.
- A remaining question is whether cider phenolics survive pasteurisation. The fact that pasteurisation in ciders takes place at high temperatures for a long time suggests that this could result in some phenolics being lost. The conclusion of a recent study was that whilst pasteurisation had no effect on polyphenolic content it did significantly reduce antioxidant activity. This is, therefore, an area for potential further research.
- Future orchard systems need to be designed to require minimal chemical input for pest and disease control. Alternatives to chemical control approaches for management of pests and diseases exist, but for this potential to be realized the most likely options need to be tested in selected orcharding systems (intensive or extensive). Intensive orcharding allows optimized spray and litter management systems and deployment of intricate biological/chemical controls, while in extensive orcharding it may be harder to apply specific biocontrols. A number of IPM packages for dessert and culinary apples are available and may have application in the cider sector, though their management cost is high for a crop where inputs are traditionally low.
- Irrespective of the planting system (intensive or extensive), there are certain generic approaches which offer opportunities for greater sustainability. These include the use of pruning waste and trash, and pomace as sources of health-beneficial polyphenolics as well as the development of biochar facilities for apple prunings and trash.
- Focused research is needed to build on the opportunities identified here; in many cases the objective should be to adapt findings from other countries/environments to the UK situation. For example, further research is needed to identify which plant species are optimal in terms of nectar and pollen source for foraging insects, in order that their populations are maintained outside periods of pest activity. This will need to be tailored

to individual parts of the country, particularly with regard to mitigation of the effects of climate change. More strategic is the development of cider apple breeding for the UK to address fruit quality needs in trees able to grow productively under conditions of predicted climate change. In addition, demonstration orchards need to be established in which research results can be brought together with best current practice for monitoring and viewing regularly be the industry. This should be carried out where the main industry activity is taking place i.e. in the West Country.

The main points from this section are summarized in Table 5.

Table 5: Conclusions and implementations

		System	
Topic/Problem	**Objective**	**Intensive**	**Extensive**
Planting	Optimize light interception (Y-shaped trees?)	✓	×
Training/Pruning	Use of pruning waste and trash, and pomace as sources of health-beneficial polyphenolics	✓	✓
	Development of biochar facilities for apple prunings and trash	✓	✓
Regularity of bearing	Research on self-fertility/biennial bearing	✓	✓
Fruit harvest	Mechanized (use of robotics)	✓	×
Pests and diseases	Area adjacent to orchard with beneficial insects	✓	×
	Alternating alley strips	×	✓
Alley grasses	Research on best plant species for adjacent area and alley strips	✓	✓
Breeding with priority to climate change resilience	Breed for reduced winter chill requirement, regular bearing, pest and disease resistance, self-fertility, water-use efficiency. Also for health beneficial polyphenolics	✓	✓

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Appendices

Appendix 1: The apple market.

The main countries producing apples worldwide in 2008 were China, USA, Turkey, Poland and Italy (DEFRA, 2010). In 2008/2009 there were 18,502 hectares of orchard fruit in the UK, 6,775 of which was planted with cider apples and perry pears, 4,935 hectares with dessert apples, and 3,806 hectares with culinary apples. The dessert apple sector is dominated by Cox's Orange Pippin, which accounts for 42% of the total planted area of dessert apples, while Bramley's Seedling is the most important variety within the culinary sector accounting for 95% of the total planted area of culinary apples. The value of home production of total orchard fruit marketed in the UK as estimated in 2008 was £149.2 million, with apples (dessert, culinary, cider) and perry pears accounting for 89%; however, only 34% of the apples supplied in the UK are home-produced. In total, 118.4 thousand tonnes of dessert apples were produced in the UK in 2008, with Cox apples accounting for 43% of them. Bramley apples accounted for 99% of the total culinary apples produced in the UK in 2008 (DEFRA, 2010).

Appendix 2: Self-compatibility loci for the cider accessions in the National Fruit Collection.

Accession name	Allele 1	Allele 2	Allele 3	Allele 4
6_16_Skyrme_s_Kernel_003_B11	2	3	0	
6_17_Slack-ma-Girdle_005_C11	5	0		
6_19_Sops_in_Wine_(B)_007_D11	3	20		
6_21_Strawberry_Norman_009_E11	2	23	49	0
6_23_Tan_Harvey_011_F11	9	40		
6_25_Taunton_Fair_Maid_013_G11	3	8		
6_29_unknown_(accessed_as_Hollow_Core)_015_H11	9	14	0	
6_32_Paignton_Marigold_004_B12	5	23		
1_11_Tardive_Forestier_011_F01	45	0		
1_13_Broxwood_Foxwhelp_013_G01	9	19		
1_15_Bulmers_Norman_015_H01	19	49	0	
1_17_Burrowhill_Early_004_B02	1	50		
1_19_Court_Royal_006_C02	3	9	0	
1_21_Red_Foxwhelp_008_D02	10	19		
1_23_Reine_des_Pommes_010_E02	7	14		
1_25_Sauvageon_(INRA_184)_012_F02	5	2		
1_27_Taylors_014_G02	24	40		
1_29_Tremletts_Bitter_016_H02	3	50		
1_3_Belle_Fille_de_la_Manche_003_B01	1	14	0	
1_5_Gross_Launette_005_C01	3	7		
1_7_Muscadet_de_Dieppe_007_D01	5	9	35	0
1_9_Omont_009_E01	3	20	0	
2_11_Brown_Thorn_011_F03	5	14		
2_13_Crimson_King_013_G03	50	0	0	
2_15_Doux_Normandie_015_H03	5	23		
2_17_Ellis_Bitter_002_A04	23	50		
2_19_Frederick_004_B04	14	35		
2_1_Backwell_Red_003_B03	7	20		
2_21_Improved_Lambrook_Pippin_006_C04	2	5		
2_23_Kingston_Black_(B)_008_D04	7	19		
2_25_Major_010_E04	3	4		
2_27_Morgan_Sweet_012_F04	2	0	0	
2_29_Nehou_014_G04	1	49		
2_31_Rougette_Douce_016_H04	19	45		
2_33_Stembridge_Jersey_003_B05	3	36		
2_35_Stoke_Red_005_C05	5	19		
2_3_Black_Dabinette_005_C03	3	9		
2_5_Breakwells_Seedling_007_D03	14	0		

Accession name	**Allele 1**	**Allele 2**	**Allele 3**	**Allele 4**
2_9_False_(received_as_Browns_Apple)_009_E03	1	19		
3_11_Cider_Ladys_Finger_002_A06	24	4		
3_14_Coat_Jersey_004_B06	1	43		
3_15_Collington_Big_Bitters_006_C06	4	14	0	
3_18_Dabinette_008_D06	3	4		
3_19_Dunkerton_Late_010_E06	3	4		
3_1_Tom_Putt_(B)_007_D05	3	4	0	
3_21_EB52_012_F06	4	5		
3_23_Fillbarrel_014_G06	3	50		
3_25_Frequin_Tardive_de_la_Sarthe_016_H06	2	7		
3_27_Genet_Moyle_003_B07	3	5		
3_29_Gros_Doux_Blanc_005_C07	1	26	51	0
3_31_Harry_Masters_Jersey_007_D07	3	24		
3_33_Improved_Dove_009_E07	3	19		
3_35_Improved_Redstreak_011_F07	10	24		
3_3_Ashton_Bitter_009_E05	5	19		
3_5_False_(received_as_Balls_Bittersweet)_011_F05	14	19		
3_7_EB54_013_G05	14	19		
3_9_Black_Vallis_015_H05	2	3	20	0
4_11_Porters_Perfection_008_D08	2	4		
4_13_Reine_des_Hatives_010_E08	1	0		
4_15_Severn_Bank_(B)_012_F08	3	9		
4_18_Somerset_Redstreak_014_G08	3	4		
4_19_Stable_Jersey_016_H08	3	46		
4_1_Le_Bret_013_G07	1	2		
4_23_Sweet_Coppin_003_B09	50	0		
4_25_Tale_Sweet_005_C09	3	50		
4_27_Vagon_Archer_007_D09	7	24		
4_29_False_(received_as_White_Jersey)_009_E09	1	9		
4_31_Yarlington_Mill_011_F09	9	0		
4_33_Hangdown_013_G09	3	5		
4_35_Hereford_Broadleaf_015_H09	9	48	0	
4_4_Maundy_015_H07	14	20		
4_5_Michelin_002_A08	5	45		
4_7_Northwood_004_B08	14	0		
4_9_Osier_006_C08	5	0		
5_10_Medaille_dOr_010_E10	5	14		
5_11_Stembridge_Cluster_012_F10	19	24		
5_13_Vilberie_014_G10	1	9	14	0
5_15_Hereford_White_016_H10	1	50		

Accession name	Allele 1	Allele 2	Allele 3	Allele 4
5_17_John_Broad_003_B11	1	40		
5_1_Pethyre_002_A10	28	31		
5_20_Ashton_Brown_Jersey_005_C11	1	20		
5_21_Broadleaf_Norman_007_D11	28	31		
5_24_Captain_Broad_(B)_009_E11	2	3	0	
5_25_Crimson_Victoria_011_F11	7	9		
5_27_Cummy_Norman_013_G11	14	0		
5_31_Dymock_Red_015_H11	2	51		
5_33_Dufflin_004_B12	9	0		
5_35_Four_Square_006_C12	1	9	20	0
5_3_Brown_Snout_004_B10	7	45		
5_5_Chisel_Jersey_006_C10	3	22		
5_7_Dove_008_D10	14	19		
6_14_Royal_Somerset_016_H12	5	50		
6_3_Langworthy_008_D12	14	31		
6_5_Pennard_Bitter_010_E12	1	19		
6_7_Pigs_Snout_012_F12	1	7		
6_9_Red_Jersey_014_G12	19	24		

Appendix 3: National Fruit Collection cider accessions.

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	FULL FLOWER	90% OVER			
Ashton Bitter	1989-129	15-May	18-May	27-May	Late September	Raised by Mr G.T. Spinks, Long Ashton Research Station, Bristol in 1947. A seedling raised from a Dabinett/Stoke Red cross. A precocious, midseason flowering variety. Fruits are of medium size and firm. Produces juice with low acidity and medium tannin.	**YES**
Ashton Brown Jersey	1992-107	6-May (6yr)	8- May (6yr)	15- May (6yr)	November	Grown at the National Fruit and Cider Institute, Long Ashton, Bristol in 1903. Trees were also grown in some Herefordshire orchards in the 1920s and 1930s. Trees are very slow coming into cropping. Fruits are small-medium in size with a sweet, astringent, woolly textured flesh. Produces a soft, full-bodied, medium bittersweet cider.	**YES**
Backwell Red	1999-053	30-Apr	02-May	12-May	Late October	An old popular cider apple named after Backwell Village, North Somerset, UK. Fruits are small-medium in size. Produces a vintage, acidic juice and a sharp, light, fruity, thin cider.	**YES**
Belle Fille de la Manche	1999-041	10-May	12-May	20-May	Mid September	Originated in France. Widely grown in Normandy. Produces a bittersweet cider.	**YES**
Black Dabinett	1989-123	07-May	09-May	16-May	November	Originated in the UK. Some trees grown in Somerset. Produces a vintage juice and a bittersweet cider.	**YES**
Black Vallis	1989-064	24-Apr	26-Apr	04-May	Mid - Late October	Grown in Somerset. A sharp cider variety.	**YES**
Breakwell's Seedling	1989-065	10 May (9yr)	12 May (9yr)	21 May (9yr)	September	Originated at Perthyre Farm, Monmouth, Wales in the late 1800s. It was propagated by George Breakwell who also introduced the variety to Bulmers as a valuable early-ripening cider variety. Trees are fairly vigorous with characteristic luxuriant, dark-green foliage. Fruit is small to medium in size. A medium bittersweet variety producing a thin, light, average cider.	**YES**
Broadleaf Norman	1992-108	12 May (7yr)	14 May (7yr)	24 May (7yr)		Presumed to be of UK origin. A fairly heavy cropping variety producing fruit of a sweet and slightly bitter taste. Makes good cider.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	FULL FLOWER	90% OVER			
Brown's Apple	1989-067	03-May	05-May	15-May	Late October	Originated in Devon. It was discovered by Mr Hill, a cider maker and nurseryman of Staverton, near Totnes, Devon. Known to have been in existence in the early 1920s. Trees are very vigourous and can therefore delay cropping. Fruits are medium sized with white flesh which often carries a red tinge especially in highly coloured fruits. Produces a medium-sharp, fruity but rather thin cider.	**YES**
Brown Snout	1989-068	21-May	24-May	30-May	Early-mid November	Thought to have originated in Herefordshire, UK. Known to have been in existence in the mid 1800s. Late flowering. Moderately biennial. Fruits are small to medium with firm flesh. Produces a bittersweet, average mild to medium cider.	**YES**
Brown Thorn	1989-069	07-May	09-May	19-May	November	Once widely grown under the name of 'Argile Grise'in the cider-producing areas of France. It was introduced in 1884 to Herefordshire by the Woolhope Naturalists Field Club and subsequently renamed 'Brown Thorn'. The fruits are small to medium in size. The flesh, which browns very readily when cut, is juicy but woolly and has a sweet and slightly astringent flavour. Produces a mild bittersweet high quality cider.	**YES**
Broxwood Foxwhelp	1989-124	29-Apr	01-May	08-May	September	Known to have been planted in the orchard of H.P. Bulmer & Co. Ltd., in the 1920s. Thought to be a sport of Foxwhelp. The small fruits produce a medium bittersharp cider and a full-bodied juice.	**YES**
Bulmer's Norman	1989-070	02-May	04-May	11-May	Mid October	Originally an unnamed variety imported from Normandy, France. It was developed by H.P. Bulmer & Co., Ltd., in Hereford, England. Fruits are medium to large. Produces a good yield but tends to be biennial. The flesh is white with a woolly texture and a sweet but astringent flavour. Triploid. Trees are very vigorous and with a spreading habit and branch breakage can occur when the crop is heavy. Susceptible to scab. Fruits produce a bittersweet, fast-fermenting medium cider.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	FULL FLOWER	90% OVER			
Captain Broad	1992-111	28-Apr	30-Apr	10-May	September	Originated in Cornwall. Traditionally planted in Devon and Cornwall and well suited to the growing conditions in the Tamar Valley. Fairly resistant to scab. A bittersweet variety.	**YES**
Chisel Jersey	1989-072	16-May	18-May	25-May	November	An old cider variety known to have been widely grown around the Martock area of Somerset. The name is thought to have derived from the term' Jay-see' which is said to signify bitter or possibly 'an apple with a nose'. A precocious variety, cropping most years. Medium sized, hard fruits ripen in November. The flesh is white, woolly, dry, sweet and astringent. Trees are vigorous with a semi-upright habit. Fruits produce a bittersweet, very astringent juice and a full-bodied and good quality cider.	**YES**
Cider Lady's Finger	1989-073	29-Apr	01-May	09-May	October	An old variety of unknown origin. Thought to have originated in the south west area of the UK.	**YES**
Coat Jersey	1989-074	08-May	10-May	18-May	Early November	Originated in Coat village, Martock, Somerset. Received by the National Fruit Trials in 1989 from Long Aston Research Station, Bristol. Trees are very vigorous. A bittersweet variety.	**YES**
Collington Big Bitters	1989-120	10-May	15-May	20-May	Late October	Originated in Herefordshire and known to have been extensively planted in some West Midland orchards. A dual purpose apple traditionally used both for cider and for cooking. It is also known as 'The Mincemeat Apple'. Fruits are described as being soft and astringent with white, woolly flesh and a mild bittersweet fruity flavour. Produces a mild bittersweet cider of moderate quality.	**YES**
Court Royal	1989-075	28-Apr	30-Apr	08-May	October	Origin unknown but once grown in Somerset, East Devon and Herefordshire. In the early 1900s it was used as a dessert variety. Fruits are slightly crisp and sweet. A triploid. Tree growth is vigorous producing a large tree. Produces a sweet fast fermenting juice.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	FULL FLOWER	90% OVER			
Crimson King	1989-076	28-Apr	01-May	11-May	Mid November	Originated in the UK in the late 19th Century. Triploid. The large fruits are sometimes used for cooking as well as for cider production. Produces a vintage, acidic juice with no astringency and a light, fruity, good quality cider.	**YES**
Crimson Victoria	1992-112	4 May (9yr)	6 May (9yr)	16 May (9yr)	Early September	Identified as Crimson Victoria by Mr R.R. Williams, Long Ashton Research Station from fruit obtained from a small private orchard at Shute, Axminster, Devon. Received at Brogdale in 1992 from Mr G.R. Rowson, Taunton, Somerset.	**YES**
Cummy Norman	1992-113	6 May (6yr)	8 May (6yr)	17 May (6yr)	Late September - Early October	Origin unknown but thought to have been raised in Cummy, Wales. Re-discovered by Bulmers. A medium bitter sweet variety.	**YES**
Dabinett	1989-077	11-May	14-May	21-May	November	Thought to have originated in the Martock-Kingsbury area of Somerset in the mid-19th Century. Believed to have been named after a Mr Dabinett. Possibly a seedling of Chisel Jersey. This variety crops regularly. Fruits have slightly crisp flesh with a sweet, astringent, strong fruity flavour when ripe. Dabinett is weak grower producing a small and spreading tree. A bittersweet variety that produces a soft, full-bodied, high quality cider.	**YES**
Doux Normandie	1989-078	08-May	10-May	17-May	October	Originated in Normandy, France. A bittersweet variety. Fruits produce a sweet, perfumed juice. Trees are vigorous.	**YES**
Dove	1989-079	15-May	18-May	25-May	Early November	Originated in Glastonbury, Somerset. Recorded in 1899 but thought to be older than this. Dove produces a vintage, sweet and slightly astringent juice and a medium bittersweet cider. Trees are of medium vigour. This variety is now rarely planted as it is rather susceptible to scab.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	FULL FLOWER	90% OVER			
Dufflin	1992-116	23-Apr	26-Apr	03-May		An old Devonshire cider apple.	**YES**
Dunkerton Late	1989-080	30-Apr	02-May	11-May	Early November	Discovered in the 1940's in the orchard of Mr Dunkerton, Baltonsborough, Somerset.The fruits produce a sweet juice low in tannin which makes a light and fruity cider. Trees are of medium vigour.	**YES**
Dymock Red	1992-115	26 Apr (8yr)	28 Apr (8yr)	8 May (8 yr)	Late September	A very old vintage cider variety originating from Dymock Village, Gloucestershire. A bittersweet variety producing a vintage juice and a well balanced, high quality cider. Trees are of medium vigour.	**YES**
EB 52	1989-081	08-May	10-May	18-May			**NO**
EB 54	1989-082						**NO**
Ellis Bitter	1989-083	09-May	11-May	20-May	Mid October	An old variety thought to have originated on the farm of a Mr Ellis of Newton St Cyres, South Devon. The large, conical fruits have white, crisp, juicy sweet flesh which is a little astringent. A medium bittersweet variety which produces a good quality cider.	**YES**
Fair Maid of Taunton	1992-136	24-Apr	27-Apr	05-May	Midseason - Late	Thought to have originated in Taunton, Somerset. First recorded in 1831. Described by Hogg in 1884 as being a dessert apple, but not of first quality. Fruits have tender, juicy, chewy flesh with a sharp and slightly astringent flavour. The fruits are described as producing an agreeable but rather characterless cider. Trees are large, tall and spreading and rather susceptible to scab.	**YES**
Fillbarrel	1989-084	28-Apr	30-Apr	10-May	Late October	Originated in Somerset, UK in the 19^{th} Century. A bittersweet cider variety. Trees are of medium vigour.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	**FULL FLOWER**	**90% OVER**			
Four Square	1992-117	01-May	03-May	12-May	Early October	Received by the National Fruit Collection, Brogdale in 1992 from Somerset.	**YES**
Frederick	1989-085	06-May	08-May	15-May	October	Originated in the Forest of Dean, Monmouthshire in the 19th Century. Slow to come into cropping and crops tend to be rather irregular. The small to medium sized fruits have crisp, white, often tinged with red flesh with a sharp flavour but no astringency. Produces a 'full sharp, fruity, good to excellent quality' cider. This variety is also considered to be excellent for making apple jelly.	**YES**
Genet Moyle	1989-087	29-Apr	01-May	10-May	Late September	An old cider variety of unknown origin. It is said to have been a popular cider variety in the 15th Century. Fruits are described as having tender, dry flesh with a sweet, slightly acid flavour. Good for baking and drying.	**YES**
Gros Doux Blanc	1999-042	25-Apr	28-Apr	07-May		Received by the National Fruit Collection, Brogdale in 1990 from Long Ashton Research Station, Bristol.	**YES**
Gross Launette	1989-088	17-Apr	19-Apr	29-Apr		Received by the National Fruit Trials, Brogdale in 1989 from Long Ashton Research Station, Bristol. Fruits are described as having firm flesh with a bitter and perfumed flavour.	**YES**
Hangdown	1992-119	10-May	12-May	22-May	Late October	Believed to have originated in the Glastonbury area of Somerset. Known in North Devon and Somerset where it is also known as 'Pocket Apple'. It is less popular today because of its very small fruits. Crops well and regularly. Once highly recommended for cider making. Susceptible to scab.	**YES**
Harry Masters Jersey	1989-089				Early November	Also known by the name 'Port Wine'. Originated in the early 1900s in Somerset where it is believed to have been raised from seed by a Mr Masters, Yarlington Mill. A vintage, bittersweet cider apple which produces a sweet, medium tannin juice and makes a very high quality cider with a soft astringency.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	**FULL FLOWER**	**90% OVER**			
Hereford Broadleaf	1992-120	04-May	07-May	16-May		Received by Brogdale in 1992 from Showering Orchard near Castle Cary, Somerset. The fruits are described as having a sweet but slightly bitter taste. Makes good cider.	**YES**
Hereford White	1991-019				Late October	Received by the National Fruit Collection, Brogdale in 1991 from Mrs Deeley, Petworth, Sussex. Produces a dark coloured cider with a rich but slightly bitter flavour.	**YES**
Improved Dove	1989-090	7 May (9yr)	10 May (9yr)	19 May (9yr)	Late October	A seedling thought to have originated in Somerset in the early 1900s. A mild, bittersweet variety.	**YES**
Improved Lambrook Pippin	1989-091	30-Apr	02-May	09-May	Early October	Originated in the village of Lambrook, Somerset. Thought to be a seedling of Lambrook Pippin. Produces a mild, sharp cider/juice.	**YES**
Improved Redstreak	1989-092				Early October	The actual origin of this variety appears to be unknown. Known to have been in existence in the 1940s. A bitter sharp variety.	**YES**
John Broad	1992-011	29 Apr (8yr)	2 May (8yr)	12 May (8yr)		A synonym of cider variety Captain Broad. Originated in Cornwall. Traditionally planted in Devon and Cornwall and well suited to the growing conditions in the Tamar Valley. Fairly resistant to scab. A bittersweet variety.	**YES**
Kingston Black	1989-093				Early November	Believed to be a Somerset apple and possibly raised at Kingston, near Taunton. This variety was introduced into Herefordshire c.1820 by Mr Palmer of Bollitree Estate, Weston-under-Penyard near Ross-on-Wye. Trees are of medium size and have a spreading habit. Susceptible to scab. Fruits are medium to small in size and produce a full bodied, excellent quality cider with a distinctive flavour.	**YES**
Langworthy	1992-123	28 Apr (9yr)	30 Apr (9yr)	9 May (9yr)	Early November	This variety is also known under the names of Sour Natural and Wyatt's Seedling. It is thought to have originated in Devon. Once a very popular variety in Somerset and Devon. Fruits produce a sweet, light cider with a good flavour.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	FULL FLOWER	90% OVER			
Le Bret	1989-094				October	This variety is sometimes mistakenly named Sweet Alford due to an error in a cider nursery some few years ago. An annual bearing variety originating from Devon in the mid 1900s. This variety is very susceptible to scab. Produces a sweet cider.	**YES**
Major	1989-125				Late September	Originated in South Devon. Once a commonly grown variety in some of the old farm orchards of Devon and Somerset. Trees are quite vigorous. Fruits are of medium size. Produces a good bittersweet cider.	**YES**
Maundy	1989-126				Late October	An old cider variety known to have been in existence in the late 1800s. Produces a bittersweet cider.	**YES**
Medaille d'Or	1989-095	14-May	17-May	28-May	November	Raised in 1865 by M. Godard, Bois Guillaume, France. It was introduced into England in 1884 by the Woolhope Naturalists Field Club. The fruits are described as bittersweet with a sweet, astringent juice, high in tannins. Produces a cider with a high alcohol content and a strong fruity flavour.	**YES**
Michelin	1989-096				Late October - November	This old popular cider apple was raised by M. Legrand of Yvetot, Normandy , France. It first fruited in 1872. It was named after M. Michelin of Paris, one of the original promoters appointed by the French Government for the study of cider fruits. Introduced into Herefordshire in 1884 by the Woolhope Naturalists Field Club. Fruits are small and pale green to yellow. Produces a sweet juice resulting in a bittersweet cider ideal for blending.	**YES**
Morgan Sweet	1989-122	05-May	08-May	17-May	August - September	Thought to have originated during the 18th Century in Somerset. Useful also as a sweet, early dessert apple. Produces an early, light cider.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	FULL FLOWER	90% OVER			
Muscadet de Dieppe	1999-043	18-Apr	20-Apr	03-May	September	Thought to have originated in France. Produces a bittersweet cider.	**YES**
Nehou	1989-097	04-May	06-May	15-May	Late September - Early October	A French cider variety introduced into the UK in the 1920s by Dr H.E. Durham for H.P. Bulmer & Co. A very precocious, biennial cropper susceptible to scab. Fruits are small to medium and soft. Harvested late September to early October. Produces a bittersweet, fruity and full-bodied cider of excellent quality.	**YES**
Northwood	1989-098	12-May	14-May	25-May	November	Thought to have originated during the 18th Century in Crediton, Devon. Produces a 'vintage' cider.	**YES**
Omont	1989-099	20-Apr	23-Apr	05-May	September	Raised by Monsieur Omont at Bourghteroulde, Normandy, France. Produces an excellent cider.	**YES**
Osier	1989-100	12 May (8yr)	14 May (8yr)	23 May (8yr)	Mid October	A bittersweet cider variety.	**YES**
Paignton Marigold	1997-015	30 Apr (9yr)	2 May (9yr)	10 May (9yr)		Originated from Paignton, Devon before 1834. Received at Brogdale in 1997 from Thornhayes Nursery, Devon. Produces a medium bittersweet cider.	**YES**
Pennard Bitter	1992-124	07-May	09-May	17-May	Early October	Originanted in Somerset. Produces a bittersweet cider.	**YES**
Perthyre	1989-101	12-May	15-May	24-May	Late October	First noted in the late 1920s in Monmouthshire. The trees have a fairly vigorous and spreading habit. Susceptible to scab and canker. Produces a mild bittersweet cider said to be 'of variable quality, sometimes excellent'	**YES**
Pig's Snout	1992-125	4 May (2yr)	6 May (2yr)	11 May (2yr)		Thought to have originated in Callington, Cornwall. A dessert and cider apple	**YES**
Porter's Perfection	1989-102	02-May	04-May	12-May	Late October-Early November	Originated in the orchard of Charles Porter of East Lambrook, Somerset in the 19th Century. Introduced in 1907. Produces a sharp juice with little astringency. Ripens late October to early November.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	FULL FLOWER	90% OVER			
Red Foxwhelp	1989-128	01-May	03-May	10-May	Mid October	A red sport of the old English cider variety 'Foxwhelp'. Foxwhelp is considered one of the premier cider making apples. Produces a bittersharp cider.	**YES**
Red Jersey	1992-126	14 May (8yr)	16 May (8yr)	25 May (8yr)	Mid October	Thought to have originated in Somerset. Trees rather prone to scab.Produces a bittersweet cider.	**YES**
Reine des Hatives	1989-103	07-May	09-May	17-May	Late September-Mid October	Raised in 1872 by Monsieur Dieppois, Yvetot, France. Introduced to the UK in the 1920s by Dr H.E. Durham and was distributed by H.P. Bulmer & Co. A biennial but precocious cropper. Produces a bittersweet juice. The cider produced form this variety is described as 'sweet or mildly bittersweet, soft and neutral but often rather thin.'	**YES**
Reine des Pommes	1989-104	29-Apr	01-May	10-May	November	A French cider variety introduced to the UK through the National Fruit and Cider Institute in 1903. The medium sized trees have a spreading habit with small drooping branches. Produces a full bittersweet cider of good quality.	**YES**
Rougette Douce	1999-044	01-May	04-May	13-May	Mid November	Originated in France. Known to have been in existence in 1893. Produces a mild bittersweet cider.	**YES**
Royal Somerset	1992-129	04-May	06-May	15-May	Late October	Believed to be of Somerset origin. Described as a traditional dual purpose apple that can be used for cooking or cider making. Long Ashton Research station reported that this variety made a first class medium sharp cider.	**YES**
Sauvageon (INRA 184)	1999-054	29-Apr	01-May	09-May		Received by the National Fruit Trials, Brogdale in 1990 from Long Ashton Research Station.	**YES**
Severn Bank	1989-105	11-May	14-May	21-May	October	Possibly originated in Herefordshire. Received at Brogdale in 1989 from Long Ashton Research Station. Fruits produce a sharp cider.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	**FULL FLOWER**	**90% OVER**			
Skyrme's Kernel	1992-131	23 Apr (9yr)	26 Apr (9yr)	6 May (9yr)	Late October-Early November	Thought to have been raised at Brockhampton, Herefordshire and possibly raised by the Skyrmes an old Herefordshire family. Fruits were sometimes used to give a special flavour to pies and puddings. The cider this apple produces is described as having a 'peculiar flavour and its aroma improves very much by keeping, but it is better mixed with other apples of its season'.	**YES**
Slack-ma-Girdle	1992-132	5 May (6yr)	7 May (6yr)	17 May (6yr)	October	Origin is believed to be either Devon or Somerset. Medium sized fruits are in use from October to December. Flesh is described as being sweet.	**YES**
Somerset Redstreak	1989-106	06-May	08-May	16-May	October	Thought to have originated in the Sutton Montis area of Somerset. As a result of its good performance in a 1917 trial at the National Fruit & Cider Institute together with good orchard performance at Burghill, Hereford, it was subsequently propagated to be included in many commercial cider orchards. The medium sized fruit ripens in October. Produces a mild or medium bittersweet cider of average quality.	**YES**
Sops in Wine	1992-133	24-Apr	26-Apr	05-May	October	A very old English culinary and cider apple.The flesh of the fruits is red as if soaked in red wine and is sweet, juicy and pleasantly flavoured.	**YES**
Stable Jersey	1989-107	05-May	07-May	16-May	Early November	An old cider variety thought to have originated from Shepton Mallet, Somerset.Produces a bittersweet cider.	**YES**
Stembridge Cluster	1989-108	30-Apr	02-May	11-May	Mid October	Originated from Sam Duck of Stembridge, Kingsbury Episcopi, Somerset. Tends to be a biennial cropper. Produces a full bittersweet cider.	**YES**
Stembridge Jersey	1989-109	08-May	10-May	18-May	Late October	A seedling which originated from the Kingsbury Episcopi area of central Somerset.Introduced by Mr W.J. Stuckey and named after the local village of Stembridge. A biennial cropper producing small to medium fruits. Produces a bittersweet cider.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	FULL FLOWER	90% OVER			
Stoke Red	1989-110	16 May (8yr)	18 May (8yr)	27 May (8yr)	Late November	This variety gained attention in the 1920s when surveys found trees growing in Rodney Stoke, Somerset. The trees are fairly vigorous and crop quite heavily. Produces a sharp, slightly astringent juice and a fine, sharp cider.	**YES**
Strawberry Norman	1992-134	17 May (9yr)	20 May (9yr)	28 May (9yr)		Thought to have originated in Herefordshire.Known to have been in existence in the 19th Century.	**YES**
Sweet Coppin	1989-112	07-May	10-May	17-May	Early November	An old variety originating in Devon. Once very common in cider orchards in the Exeter area. Susceptible to mildew. The medium to large fruits ripen early November. Produces a pure sweet, sometimes a very mild bittersweet cider of good quality.	**YES**
Tale Sweet	1989-113	30-Apr	02-May	10-May	Early November	Originated from Tale, near Honiton, Devon. Produces a sweet juice.	**YES**
Tan Harvey	1992-135	25 Apr (9yr)	28 Apr (9yr)	9 May (9yr)	Early October	Trees found in 1980 by James Evans in the Tamar Valley, Cornwall. A good, reliable, heavy cropping cider apple which produces a bittersweet cider.	**YES**
Tardive de la Sarthe	1989-086				Late October -Early November	Believed to have originated in France.Produces a bittersweet cider.	**YES**
Tardive Forestier	1989-114	23-Apr	25-Apr	05-May	November	An old French cider apple. Produces a bittersweet cider.	**YES**
Taylor's	1989-115	03-May	05-May	13-May	October	An old Somerset variety originating from the South Petherton area. Sometimes called Taylor's Sweet. Susceptible to mildew. The medium sized fruits are harvested in October. Produces a sweet, mildly bittersweet cider of fair quality.	**YES**
Tom Putt	1989-116	30-Apr	03-May	12-May	Late August - Early September	A culinary and cider apple. Raised by Rev. Tom Putt, Rector of Trent, Somerset in the late 1700s. In use from September to November. Fruits have crisp, juicy, acid flesh. Cooks well. Produces a sharp cider.	**YES**

Cultivar Name	Acc. No.	10 year Flowering mean			Harvest date	Fruit Description	Propagation material available
		10% OPEN	**FULL FLOWER**	**90% OVER**			
Tremlett's Bitter	1989-117	27 Apr (9yr)	29 Apr (9yr)	8 May (9yr)	Early October	Originated in the Exe Valley, Devon. Flowers are very sensitive to frost which may contribute to the trees biennial cropping pattern. Susceptible to scab. Produces a full bittersweet cider.	**YES**
Vagon Archer	1989-172	11-May	14-May	23-May	Early November	Received at Brogdale in 1989 from Long Ashton Research Station. Produces a mild bittersweet cider.	**YES**
Vilberie	1989-118	21-May	24-May	01-Jun	Mid November	A French variety introduced to Herefordshire by the Woolhope Naturalist Field Club at the end of the 19^{th} Century. Trees are vigorous with an open spreading habit. Appears to be susceptible to mildew. Produces a full bittersweet cider with a good full-bodied flavour.	**YES**
Yarlington Mill	1989-119	02-May	04-May	12-May	October - November	Originated in the village of yarlington, in the North Cadbury area of Somerset. A strongly biennial cropper unless pruned regularly. Produces a medium bittersweet cider.	**YES**

Appendix 4: Example of a Pedimap data file from http://www.rosaceae.org/bt_pedigree/pedimap_select

All keywords are shown in UPPERCASE

POPULATION = pedimap_input.txt

UNKNOWN = *

NULLHOMOZ = $; this is the default

PLOIDY = 2 ; this is the default

PEDIGREE

NAME	FEMALE	MALE
"Cox"	*	*
"Clivia"	"DrOldenbu"	"Cox"
"Fiesta"	"Cox"	"Idared"
"IngMarie"	"Cox"	*
"JamesGr"	"Cox"	*
"KidsOrRed"	"Delicious"	"Cox"
"NJ303955"	"Cortland"	"Cox"
"Suncrisp"	"GoldenDel"	"Cox"
"Cortland"	"McIntosh"	"BenDavis"
"Delicious"	*	*
"DrOldenbu"	*	*
"GoldenDel"	*	*
"Idared"	"Jonathan"	"Wagener"
"BenDavis"	*	*
"McIntosh"	*	*
"Wagener"	*	*
"Jonathan"	*	*