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Review and report of current ICM and 'best practice' in soft fruit

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History and Development of IPM

Before reviewing current practices in Integrated Pest Management (IPM), it is important to understand the historical perspective of how the term developed. The underlying principles of IPM were developed well before the term 'IPM' was first used. As far back as the late nineteenth century, crop protection specialists recognised the need to understand pest biology and cultural practices, allowing them to produce control strategies that incorporated many different tactics to limit and control the number of pests present (Kogan, 1998).

Priorities changed in the early 1940s, with the development of synthetic insecticides, which lead to the old methods of pest biology, such as monitoring and understanding pest biology which was developed in the 19^{th} century, and natural ways of controlling pests, being pushed aside. However, in the early 1960's fears developed over the reliance of pesticide use and reports of insect resistance suggested that dependence on insecticides was not going to be the long-term answer. Despite this, the application of chemical pesticides has become the dominant form of pest control in developed countries and is increasing in developing countries. In parallel with this, insecticide resistance is found in 500 insect species worldwide (Thomas, 1999).

Fears over the environmental damage and possible health concerns caused by chemical insecticides and pressure from retail and consumers, has lead to the banning and restricted use of many pesticides. However, 30-40% of the world crop production is still lost to pest and disease (Thomas, 1999), suggesting that the need for pest control which is not completely reliant on chemical pesticides is urgently required.

Integrated control, as a concept was first developed by Hoskins *et al.*, (1939) (cited in Kogan, 1998). This concept indicated that the main method of controlling pests in agriculture should consist of biological methods and that although chemical control is required, it should be limited in its use as much as possible.

Throughout the years there has been much debate over the definition of Integrated Pest Management and over the choice of words used in the phrase "integrated pest management" (Kogan, 1998). A survey by Bajwa and Kogan (1996), suggested that there are 64 definitions of integrated control, pest management or integrated pest management. Using the Science Citation Index, they found that the most often cited definition is Stern *et al'*s (1959). In 1967, the FAO panel of experts broadened Stern *et al'*s definition to: "Integrated Pest Control is a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest population dynamics below those causing economic injury." To date, a consensus about the definition is still to be reached (Kogan, 1998) and this may be hindering the implementing of the correct criteria in IPM programs around the world (Benbrook et al., 1996 cited in Kogan, 1998).

What is an IPM system?

An IPM system must aim to provide a grower with an economic and appropriate means of controlling pests below economically damaging thresholds. The successful development and adoption of an IPM system relies on the combined knowledge of many different disciplines and an understanding of how these individual components interact (Dent, 1995). Integration can occur at many levels. At the simplest level, it can mean the monitoring of pest populations or weather conditions to predict pest outbreaks and the application of pesticides at the appropriate times to control the pests. At the uppermost level, it can mean the communication of researchers from many countries developing regulations on pesticide use or developing novel methods such as biological control and genetic resistance to control the pests (Reuveni, 1995).

Adoption of an IPM system

The adoption of an IPM system in any agricultural system can be split into four blocks, which allows the measurement of the progress of the IPM system by calculating the average per hectare pesticide use and the risk levels within each section (Lynch, 1998). The potential environmental and public health benefits during the progress of the IPM system can be approximated by subtracting average per hectare pesticide use data in the No or Low blocks from comparable data drawn from fields in the Medium or High blocks. Figure 1 shows the progress through the adoption of an IPM system resulting in a reduced reliance on pesticides.

<table>
<tr><td rowspan="2">No IPM</td><td colspan="2">←Transitional systems→</td><td rowspan="2">High or
Biointensive IPM</td></tr>
<tr><td>Low</td><td>Medium</td></tr>
<tr><td colspan="4">→→→ Shifting Reliance From Treatment to Prevention →→→</td></tr>
<tr><td colspan="4">Chemical Based →→→ →→→ →→→ Biological Based</td></tr>
</table>

Figure 1. Progress through the adoption of an IPM system shifting from a reliance of pesticides to the prevention of pest outbreaks (Lynch, 1998)

The use of pesticides

The position of Pesticides in Europe

Pesticides cannot be sold in the UK with out an approval from the government. Until 1991, this was the responsibility of the UK authorities but this responsibility has been moved to the European Commission who now organises a major part of the safety evaluation (Buffin *et al*., 2003). This system was introduced through the European Union Agricultural Pesticides Directive, 91/414. This directive aims to regulate the registration, sale and approval of agricultural pesticides across the European Union. They pledged to achieve substantial reduction in the use of pesticides, but until 2002, the Commission had not taken any further legislative action concerning pesticides. Such organisations, for example, The Pesticide Action Network (PAN) Europe and the European Environmental Bureau (EEB), believe that the Commission is not setting enough targets for the actions it proposes.

In response to the European Commissions Communication "Towards a Thematic Strategy on the Sustainable Use of Pesticides", released in 2002, PAN Europe and the EEB have drafted a detailed pesticides use strategy in the text for a Directive on Pesticides Use Reduction in Europe (the PURE directive) (Pan Europe, 2002). Their directive suggests that *inter alia* supported is needed as there is increasing evidence that pesticide use poses a threat to children's health and is causing increased contamination of groundwater. Their suggested actions include:

"Mandatory reduction plans for all Member States with targets and timetables for reduction and increased percentage of land in organic farming, including, for each Member State, a target reduction of 50% of the treatment frequency index within 10 years from a baseline year;

IPM/ICM as a minimum for all EU non-agriculture and agriculture PPP uses;

Cross-compliance with ICM as a condition for CAP subsidies; more agri-environmental support under CAP to go beyond ICM, e.g. to promote organic farming;

Full access to information on pesticides held by authorities, including information supporting specific regulatory decisions in due time to allow for responses from the general public, and participation of public interest groups, as observers, in all meetings where decisions are taken related to pesticides and their use." (Pan Europe, 2002)

The European Commission is to propose at the beginning of 2004 all the necessary measures, setting out a comprehensive Community Thematic Strategy on the Sustainable Use of Pesticides, but many doubt that the Commission will keep to their deadline. However a recent communication from the Commission on the sixth environment action programme of the European Community (EC communication, 2001) has outlined their proposals for the future Community Thematic Strategy. Elements of this are likely to include:

- Minimising the risk from the use of pesticides, which is principally linked to the toxicity of the substances, and monitoring progress;
- better control of the use and distribution of pesticides;

- substituting the most dangerous active substance with safer ones, including non-chemical alternatives;
- raising awareness of, and training users;
- encouraging the uptake of low inputs or pesticide free agriculture and the use of Integrated Pest Management techniques;
- encouraging the introduction of fiscal incentives to reduce the use of the most dangerous pesticides such as a pesticides tax;
- linking the award of Rural Development Funds to the uptake of the Code of Good Practice on pesticide use.

The Community has already adopted a number of legislative acts aims at controlling adverse impacts from the use of pesticides e.g. Directive 91/414/EEC and Directive 98/8/EC. Unfortunately, there is a delay in the evaluation of products and undertaking of these Directives means that 'problem' pesticides still remain on the market. PAN Europe suggest that experience shows that the control set in place by these acts are not sufficient to prevent contamination of water, air, and soil by pesticides. They warn that the use of pesticides in Europe is increasing, with serious environmental problems and knock on effects on biodiversity, phytotoxicity and human/animal toxicity.

Pesticide sales in Europe

A report by Eurostat (Eurostat/NewCronos data, 2002, cited in EEA, 2002) claims that annual pesticide sales in EU countries have increased, from 295 289 tonnes to 326 870 tonnes of active ingredients, between 1992 and 1999. There was a decrease between 1992 and 1995 which was partly due to the increase in use of low dose pesticides and specific policies in some EU countries, which aimed to reduce the amount of pesticides used. Since 1996, there has been an increase in the number of pesticides showing a general trend in an increased reliance on pesticides and therefore an increase in exposure to the environment.

Pesticide contamination

Water

A survey carried out in 2001 by EUREAU, an organisation that represents the water industry associations across Europe, showed that pesticide contamination is severe in the UK, Belgium, France and the Netherlands (EUREAU, 2002). In these countries between 5-10% of resources regularly contain pesticides in excess of 0.1 μ g/l. In the UK, the chemicals that regularly cause problems in ground water supplies are atrizine, bentazone, mecoprop, simazine; and for rivers – atrizine, chlortloluron, diuron, glyphosate, ispoproturon, MCPA and mecoprop.

Pesticides have also been found in rainwater. Altogether, 44 pesticide active ingredients have been found in European rainwater from 1990 onwards (Dubus *et al.*, 2000, cited in Pan Europe, 2002). Soil contamination is also a problem, as some pesticides accumulate in the soil to form products which harm the soil itself or can kill non-target species.

Food

Pesticide residues in food is a major concern across Europe. A DG SANCO report (2001) identified what residues occurred most frequently. Chlorpyrifos was identified in 12 countries and another frequently detected pesticide was DDT, which has been banned since 1984.

Biodiversity

It is well known that pesticides have serious effects on biodiversity, effecting a wide range of non-target organisms such as birds, fish and beneficial insects. Studies into organic farming in Germany suggests that biodiversity is greater in areas closer to organic farming than conventional farms (Frieben, B and Kople U., 1997, cited on Pan Europe , 2002)

Trends in Pesticide use

As an example, figure 2 below shows the total area of soft fruit treated with formulation in Scotland between 1980 and 2001 (SASA, 1990-2001). Although the number of hectares of soft fruit grown in Scotland has decreased between 1980 and 2001, there is a general trend towards an increase in the use of pesticides. The only exception is the year 2001, which saw a decrease in the amount of pesticides applied. This will be due to the number of pesticides being withdrawn from use.

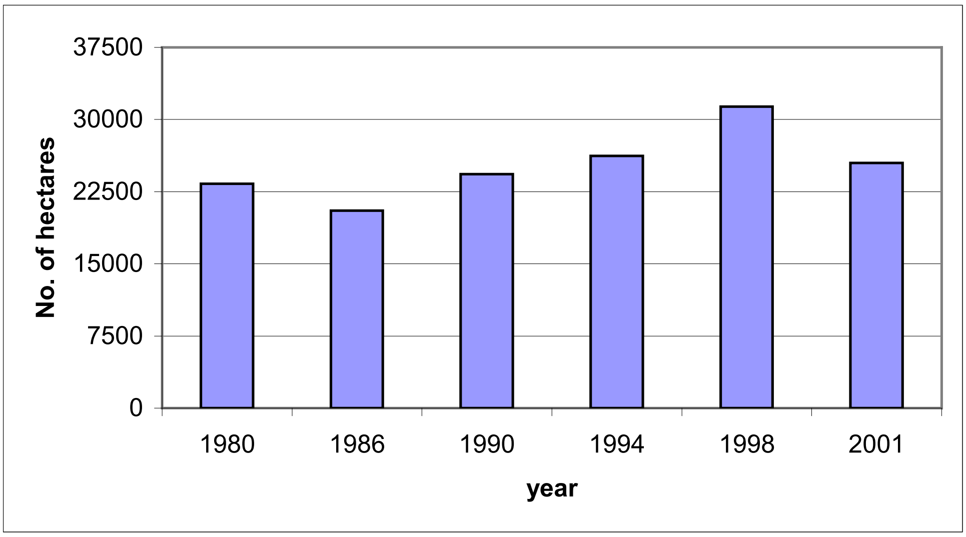

Figure 2. Total area of soft fruit production treated with formulation in Scotland between 1980 and 2001.

Pesticides withdrawn from sale

For an active ingredient to make it through the review process the pesticide manufacturers must support their pesticide by providing sufficient environmental and safety data to prove that their products meet current safety standards.

An analysis by Friends of the Earth and the Pesticide Action Network showed that many of the 320 pesticide active ingredients that are being withdrawn from July 2003, are not being withdrawn because of the need to remove dangerous chemicals, but primarily down to economic decisions by the pesticide manufacturers.

These active ingredients are not allowed to be used on farms after the 31st December 2003. However, it is unlikely that farmers will have used up all their stock by then and requirement for the farmers to pay for the disposal of the chemicals suggest that the banned substances will still be used after this date.

Evaluating a Pesticide

Penrose *et al*. (1994) proposed a rating system, which allowed the identification of less desirable pesticide use. They believed that this was required as previous guidelines only rated the pesticides by the problems that they may cause and did not take into consideration the benefits from using a certain pesticide. This proposed rating system would allow an objective implementation of pesticide reduction strategies, where the more benign pesticides would be favoured. When considering the reduction of residues in fruit, the following attributes that need to be taken into consideration: the amount of active ingredient per hectare of application, site of application, time of application, toxicity, persistence, mode of action, environmental effects, efficacy, cost, compatibility with IPM and availability of alternative pesticides. However, these attributes are not important in all situations. For example, if the aim is to minimise the risk to a farmer or worker, another set of attributes will become important. They produced a rating system that copes with the different attributes. It consists of the Potential for Residue Index, which indicates the potential for residue problems, and the Value Index, and this gives an estimate of the value or importance of the pesticide in any given crop production system.

IPM in the bigger picture

IPM is thought of as a component part of Integrated Crop Management (ICM). IPM is the component that focuses on the pest management aspects of the whole ICM system. This in turn is encapsulated by Integrated Farming Systems (IFS) which incorporates the whole farm approach including crops and livestock. These systems and interactions between them and will result in sustainable agriculture. The most widely quoted definition of sustainable development is the World Commissions' on Environment and Development of 1987, "Sustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs".

ICM production lies somewhere between conventional production and organic production, but its exact position is still widely debated (see Table 1). In one sense, ICM production is much closer to organic production as they are both methods designed to reduce the negative impact of pesticides and other synthetic inputs on the environment. However, in another sense they have two very distinct origins. Organic production was developed as a distinct alternative to conventional production by a few ecologically minded people, who believed the old methods were too harmful to the environment. ICM was also developed in response to the perceived problems of conventional practices, but instead of being a radically different approach, ICM uses and expands on the concepts of good agricultural practice already in place.

	Organic Agriculture	ICM Systems	Conventional Agriculture
Practice **Production techniques**	Non-use of inorganic inputs. Emphasis on the sustainable use of resources and farm animal welfare	Technologically intensive set of production techniques which emphasise equally environment, farm incomes and food quality	Emphasis on the application of technology to increase yields, productivity and profits
Knowledge requirement	Radical break with conventional farming knowledge networks. Requires the development of a new R&D and advisory system. Local/tacit knowledge based.	Demands new developments within the existing advisory system and more targeted R&D. Possible re-training needed if enterprise mix alters. Mix of local and external knowledge.	Traditional R&D and advice (public and private sectors). Standardised knowledge base.
Promotion Policy structures	Can benefit from the CAP commodity regimes. 88% of organically farmed land receives support through EC Regulation 1257/99.	In addition to support under the CAP commodity regimes there is support under 1257/99 in some member states. Also modest support for R&D and technology transfer through organisations represented on IACPA.	Supported under the CAP commodity regimes.
Market structures	Niche markets	Principally mass food market structures (e.g. farm assurance schemes based on IFS), but potential for niche marketing opportunities (e.g. regional labelling schemes)	Mass markets for conventional food products.
Conceptual issues **Ideas underpinning practice**	Initially a deliberate and radical critique of conventional of conventional methods of food production, marketing and consumption. Now defined by EU Regulation. Sustainable resource use for food production is key aim.	Environmental considerations given greater emphasis within food production. A relatively more sustainable use of resources for producing food than conventional agriculture.	Productivism through intensification, specialisation and concentration.
Relationships within the food chain	Aims to draw consumers closer to producers. Potential for producers to exert more control within the food chain supply through alternative methods of marketing,	IFS is in part response to consumer concerns about production methods. Potential for consumers to be brought slightly closer to producers through labelling schemes	Consumers distant from producers. Producers occupy a potentially more marginal position within the food supply chain.

	price premiums.	based on IFS. Producers position in food supply chain slightly improved e.g. through quality assurance schemes.	

Table 1. Summary of differences between conventional, integrated and organic systems (Agra CEAS Consulting, 2002).

An example of an organisation that has been set up to promote ICM is LEAF (Linking Environment and Farming). This organisation was set up in 1991 to bridge the gap between consumers and farmers. The purpose of LEAF was encouraged by a common concern for the future of farming and keenness to develop a system of farming which was realistic and attainable for the majority of farmers. This idea was based on work in Germany that had been carried out since 1986, which was established to develop and promote Integrated Farm Management.

The proportion of ICM in the EU is small, under 3% of Utilisable Agricultural Area (UAA) and there is considerable variation between different countries. For example, Denmark has by far the largest proportion of UAA, 23%, whilst Greece has no ICM. (Agra CEAS Consulting, 2002).

A broad view of IPM in agricultural systems

Countries differ in the amount of research and development they presently put into IPM. For example, in the United States, IPM development and implementation in three of their important crops, cotton, sorghum and pecan has been developing for 25 years (Harris, 2000). Most of the programmes that exist today were made possible by major funding by public bodies in the early 1970s. A simple web search indicates the amount of progress done on a large variety of crops in the United States. In the UK and the rest of Europe, research and development of IPM is still in its infancy when compared with the United States.

There is a great emphasise on developing IPM systems in developing countries due to an increase in the use of chemical use in agriculture during recent decades. Much of this is used on cash crops, such as vegetables, rice, cotton, bananas, coffee and cocoa, which is destined for export or local markets (PMN No. 2, 1998). The regulations for the use of pesticides in developing countries is not as well developed as in other countries and as a result there is often environmental contamination and severe health problems. Many of the problems arise from instructions not being in the correct language, illiterate farmers and often the instructions are very difficult to understand. Protective clothing is expensive to buy and the hot and humid conditions make protective clothing impractical (Eddleston, 2002). A number of groups have been set up to develop IPM systems in developing countries. A European group called IPMEurope, which is made up of institutions of the European Commission and some European Union member states, are interested in coordination European support for research and development in IPM in developing countries. In the United States, the Consortium for International Crop Protection, CICP, was formed by a group of universities to help advance economically sound practices in developing countries whilst protecting the environment. In 1996, an international collaboration was set up to help promote the exchange of information between research organisations to help develop IPM systems in developing countries. This collaboration included CICP, the IPMForum, a number of international agricultural research centres and IPMEurope.

IPM in coffee production in developing countries is an example of work funded by the European commission (PMN No. 9, 1998). As with many insect pests, resistance to pesticides has been found and outbreaks of pests due to pesticides killing natural enemies has been observed. Not all strategies are new. Biological methods of control of the coffee mealy bug, *Planococcus kenyae*, has been successful in Uganda. A parasitic wasp, *Anagyrus kivensis* was introduced in 1939 and the population of the pest was under control by 1949 (Wrigley, 1988., cited in PMN No. 9, 1998). Another method used in coffee production is a more selective use of pesticides to conserve the number of natural enemies. Chemicals can also be used more selectively, for example, the stem treatment of coffee bushes against the ant, *Pheidole punctulata*, by painting a band of insecticide around the lower part of the coffee stem (Cambrony, 1992., cited in PMN. No. 9, 1998). The ants foraging from the ground cannot cross this barrier but the predators that live in the leaf canopy and the flying insects are not harmed. There are also several cultural control methods developed for specific pests. One example of this is the control of the coffee berry borer. This borer survives from one season to the next in berries that have either dropped to the ground or been left on the tree after harvest. To control this pest, the overripe berries are picked from the tree or the surrounding ground to reduce the numbers of the pest that survive. There has also been work on developing resistant cultivars to such diseases as the coffee berry disease and coffee leaf rust disease (PMN no.9, 1998).

IPM systems will vary depending on the type of crop grown. For example, the control of pests in an annual crop will have some differences when compared to the control of pests in a perennial system (see Table 2) .

Soft Fruit (perennial crop)	Cereal (annual crop)
Perennial system where long term pest control measures can be set up.	Annual system with crop rotation which means that pest control on one crop may influence events on the next.
Soft fruit are a high value crop, entering a niche market including fresh, frozen and processed.	Over production in Europe means reduced price so solutions to pest problems that involve a reduction in costs are welcomed.
The long-term development of plantations means that pest populations can increase over years. Many of the pests use the crop at every part of their lifecycle.	Cereal pests are usually primarily associated with grassland and are referred to as 'ley' pests. Therefore many pests are less important in intensive cereal systems where grass in minimal.
Factors which effect pests – weather, cultivation practices, cultivar, quality of plants.	Factors which effect pests - weather, soil type, rotation, sowing date, manuring, quality of seed.

Table 2. The comparisons between a perennial system (soft fruit production) and an annual system (cereal production).

It is impossible to cover IPM systems in use in all crops so this review will be restricted to IPM in the three major soft fruits crops in Europe, raspberry, strawberry and blackcurrant. It will also be confined to looking at arthropod pests of these crops. However, to make a comparison between the amount of work done in soft fruit with other fruits, IPM systems in apple will be discussed.

IPM in Soft Fruit

Raspberry - general

Raspberries are an important high value crop, which is grown across a large area of Europe. In 2001, the estimated production of raspberries in the UK was ca. 31,000 tonnes (DEFRA, 2001). Much of the fruit is grown for the fresh market but an increasing proportion is destined for processing methods such as freezing, canning, sulphur-dioxide- treated pulp and juice production. As it is a perennial crop the population of many pests can soon build up if they are not suitably controlled. At present raspberry growers are dependent on organophosphates and the carbamate aphicide pirimicarb (Aphox) (Cross & Jay, 1998).

Arthropod pests were less of a problem when the growth of the crop was restricted to the cooler areas of Europe but as new varieties were developed that could be grown at high temperatures the pests become more of a problem (Gordon & Woodford, 1990).

Arthropod pests of raspberries cause both direct and indirect damage, e.g. viruses and contamination, and therefore a loss in value. With a decline in the number of products approved for use in raspberries, alternative methods are required to control the arthropod pests. There has been research into controlling some insect species by scouting and forecasting but there has been limited expansion of these trials onto farms. Current strategies and developments in IPM and future possibilities are discussed below for the main pests of raspberries.

Strawberry - general

The cultivated strawberry, *Fragaria* X *ananassa,* is a result of crosses between two native American species (Simpson, 2002). Due to extensive breeding work, it is now possible to grow strawberries in many climates ranging from the temperate Mediterranean to sub-tropical and taiga zones (Hancock *et al*., 1992). Unfortunately, traditional breeding practices have resulted in a small germplasm base. This lack of genetic diversity means that the plants are vulnerable to diseases, pests and diseases (Scott and Lawrence, 1975 cited in Watt, 1999). To overcome this, new gene sources from wild species have to be incorporated into breeding programmes but because the process of genetic breeding takes a few generations it is a lengthy process (Watt, 1999).

The total production of strawberries in the UK in 2001, was 80 000 tonnes (DEFRA, 2001). Pest management in strawberry production has relied on a small number of organophosphorus and carbamate insecticides. The use of some of these pesticides on strawberry production have been or will be banned, so other methods of controlling pests are seriously needed (Cross *et al*,. 1998)

Blackcurrant - general

The blackcurrant, is part of the genus, *Ribes*, which is split into into six subgenera, all of which are woody shrubs. Of all the species in the genera, blackcurrant is by far the most important commercially (Brennan *et al*., 2002). At present, IPM is hardly used in the production of *Ribes*, due to the need to use chemicals to control a very important pest, *Cecidophyopsis ribis*, the blackcurrant gall mite (OEPP/EPPO Bulletin, 2002).

New Heading RequiredThe list of arthropod pests on these three crops is quite extensive and there is an array of chemicals which are used to control them (Table 3). This list of chemicals has been reduced over recent years and will no doubt be reduced even further in the coming years.

Pests	**Insecticides used to control them**
sawflies: *Nematus ribesi, N. olfaciens, N. consobrina, Pristiphora rufipes*	lambda-cyhalothrin, malathion, parathion, tortenone
currant clear wing moth (*Synanthedon tipuliformis*)	fenpropathrin, malathion
black-currant leaf midge (*Dasyneura tetensi*)	dimethoate, fenpropathrin, parathion
black-currant stem midge (*Resseliella ribis*)	dimethoate, fenpropathrin, parathion
rose tortix (*Archips rosana*)	sprays against sawflies generally effective
currant moth (*Lampronia capitella*)	lambda-cyhalothrin, malathion, parathion, tortenone
winter moth (*Operaphtera brumata*)	diflubenzuron
capsids: *Lygocoris pabulinus, Plesiocoris rugicollis, Lygus rugilipennis*	chlorpyrifos
vine weevil (*Otiorhyncus sulcatus*)	lambda-cyhalothrin, malathion, parathion, tortenone
woolly currant scale (Pulvininaria ribesiae)	tar oils
Mites: *Tetranychus urticae, T. atlanticus*	bifenthrin, clofentezine,dicofol, chlorpyrifos, dimethoate, fenpropathrin. lambda-cyhalothrin, oleic acid, petroleum oils, propargite, tetradifon
black-currant gall mite (*Cecidophyopsis ribis*)	fenpropathrin
raspberry beetle (*Byturus tomentosus*)	chlorpyrifos, deltamethrin, rotenone
strawberry blossom weevil (*Anthonomus rubi*)	deltamethrin, lambda-cyhalathrin
stem gall midge (*Lasioptera rubi*)	alpha-cypermethrin, deltamethrin, lambda-cyhalothrin
raspberry cane midge (*Resseliella theobaldi*)	chlorpyrifos
raspberry moth (*Lampronia rubiella*)	chlorpyrifos. deltamethrin, tar oils
bramble shoot moth (*Epiblema uddmanniana*)	*Bacillus thuringiensis*, chlorpyrifos, tar oils
clay-coloured weevil (*Otiorhynchus singularis*)	lambda-cyhalothrin
Aphids: *Aphis idaei, Amphorophora idaei, A. rubi and Sitobion fragariae*	chlorpyrifos, chlorpyrifos-methyl, deltamethrin, lambda-cyhalothrin, lambda-cyhalothrin + pirimicarb, oleic acid, petroleum oils, pirimicarb
two-spotted spider mite (*Tetranychus urticae*)	clofentezine, chlorpyrifos, dimethoate, oleic acid, petroleum oils, tetradifon.

Table 3. The pests of Ribes and Rubus and the pesticides use to control them. (OEPP/EPPO Bulletin, 2002).

IPM systems

This review discusses work on producing IPM systems for insects pests of *Ribes* and *Rubus.* IPM system in *Rubus* and *Ribes* is still in its infancy in Europe. There are some separate components of IPM systems available but the work has yet to mould together to produce a sound IPM system for any crop which can cope with a reduction and careful use of a restricted number of pesticides, but still keep pests at an economically viable level.

The following section indicates the most important pests found on *Rubus* and *Ribes* and discusses strategies used to control them.

Large raspberry aphid (*Amphorophora idaei* (Borner))

A. idaei is the most important aphid species found on raspberry plants in Europe. The eggs are laid near the base of the vegetative canes at the end of the year and hatch in the following spring. Several generations are produced throughout the summer, by asexual reproduction, and the maximum numbers are found at harvest time. Some of the individuals produced are winged aphids, which migrate to new feeding sites during the summer. Although large populations found on susceptible cultivars can cause direct feeding damage, the main problem is caused by the transmission of four raspberry viruses (raspberry leaf spot virus, raspberry leaf mottle virus, black raspberry vegetative necrosis virus and rubus yellow net virus) while the aphids feed on the plant tissue (Gordon *et al*., 1997).

In this case, resistance genes to *A. idaei* are being used as a strategy to reduce the amount of pesticides used. Cultivars containing resistance genes to the large raspberry aphid have been in use for over 40 years. This resistance was largely dependent on single major genes, which when bred into raspberry cultivars, provided a means of controlling aphid numbers and the viruses they transmit. However, virulent biotypes of aphid that can overcome the resistance have developed. In the 1960s, Briggs (1965) uncovered the genetic bases, which enabled *A. idaei* to overcome the plant resistance. He found that 3 % of aphids had virulence genes. A recent survey suggests that this number now stands at 77 % and molecular genetics have provided a likely explanation of the cause of this increase in numbers. It is likely that the change from using susceptible cultivars to using resistant cultivars has enhanced the spread of the virulent gene through the population (Birch et al, 1992, 1994 cited in Jones et al., 2000). However, cultivars which contain the same resistant genes have been shown to respond differently to the changing situation in the field. For example, four cultivars growing in the same area that were reported to contain gene A1 which confers resistance to the A1 biotype of *A. idaei*, showed differing levels of resistance to this pest. Large numbers of *A. idaei* were found on the cvs. Glen Moy and Glen Prosen, while there were very few found on cvs Delight and Malling Landmark (Birch and Jones, 1988). A study into the possible reason behind this diminishing resistance (Jones et al., 2000), suggests that the genetics for resistance and susceptibility is more complex than proposed by Briggs (1965). The effects of a single major gene may be modified by other background genes and by the plant's environment (e.g. Degrees of shading).

The current research in this area suggests that the populations of *A. idaei* have great genetic variation and can overcome the resistance genes currently being used in commercial raspberry cultivars. Plant breeders will have to continue to search for new sources of genetic variation so that plant resistance to this pest can remain part of an IPM system in this crop.

Raspberry beetle (*Byturus tomentosus* (Degeer))

B. tomentosus is a major pest of raspberry plants and is found in many countries in Europe. After overwintering in the soil, the beetles emerge in the spring before the plants are flowering. The newly–emerged beetles remain in the young foliage at the base of the plant until their cuticle harden, providing them with enough protection from the environment to forage on the aerial vegetation. They continue to feed on the foliage until the flower buds open. The adults lay up to 120 eggs, usually with a single egg, on the stamen or style, per flower. Although the adults feeding on the leaves cause some damage to the plant, the most damage is the result of the larvae feeding. The newly hatched larvae feed at first on the surface of the developing fruit, then tunnel into the developing fruits where they feed on the inner surface of druplets of the developing fruit causing deformed and discoloured fruit. When the larvae are fully fed, they fall to the ground and pupate in the soil. There is usually one generation a year (Taylor, 1971).

The raspberry beetle was satisfactorily controlled at first by Rotenone (Steer, 1932), DDT (Shaw, 1945) and malathion (Dicker, 1969, cited in Taylor and Gordon, 1975). After the withdrawal of DDT, an alternative, fenitrothion, was shown to successfully control larval infestations if applied at the first pink-fruit stage (Taylor, 1971). Further trials in 1971 and 1972 (Taylor, 1975) using fenitrothion suggested that sprays applied between 80% petal-fall and first pink-fruit stage was most successful. It was also noted that application of chemicals at this time left only a negligible residue. This study optimised the use of pesticides but the timing of the spray was a danger to the pollinators.

An EU project called 'Reduced Application of Chemicals in European Raspberry Production (RACER)' in 1998-1999, used white, non-UV reflective sticky traps with the aim of developing thresholds based on the relationship between the number of trapped raspberry beetles and the amount of fruit damage. Raspberry beetles use visual and olfactory cues to locate raspberry flowers and these traps represent a raspberry flower, therefore attracting the beetles. Traps were placed in insecticide-free plots in plantations at the first-flower bud stage in sites in Scotland, Switzerland and Finland. There was found to be some correlation between the number of beetles trapped and the amount of fruit damage. The study found that during flowering, the beetles are more attracted to the flowers than the traps. The traps become obscured by the foliage so the number of beetles caught is not a true indication of the numbers present during flowering.

The use of sticky traps to control raspberry beetle was investigated further by Woodford *et al*. (2003). In addition to the white, non-UV reflective sticky traps, flower volatiles that were identified as attractants, by using automated thermal desorption (ATD), gas chromatography (GC) and mass spectrometry (MS) (Birch *et al*. 1996), were also used to enhance the traps. The results showed that traps baited with the chemical caught significantly more beetles than the control traps. The lure increased the number of beetles caught before flowering by a factor of 5-20 times, and by a factor of 1.5-4 times after flowering had started. These volatile-enhanced traps could lure beetles from a distance of at least 5 metres (Woodford *et al*., 2003). In one set of trials with two volatile enhanced traps and two traps without lures, exposed for 4 days in 17.5m row lengths of cv. Glen Rosa, resulted in the removal of 350 raspberry beetles per replicate. The percentage of damaged fruit harvested from these rows was significantly less than in the control rows. These findings suggest that future work to optimise the trap design and placement could provide a strategy to keep the number of beetles to below economic threshold and reduce the need to apply insecticides.

Raspberry cane midge (*Resseliella theobaldi*)

The larvae of *R. theobaldi* over winter and cocoon in the soil at the base of the plants. After a short pupation the males emerge first and then mate with the females when they emerge later. The females position the eggs in the splits and wounds in the bark at the base of the young stems. The larvae hatch and feed on the outer cortex tissue protected by the covering of bark. Once the larvae are fully fed, they drop to the ground to pupate. Between two and four generations can take place in the year, with the exact number being dependent on the season and location. The second generation is usually the most abundant because of the fresh new splits that appear and the fast growing primocanes provide abundant sites for ovipostition. The damage caused by the feeding larvae predisposes raspberry canes to a disease known as "midge blight". This is caused by a range of fungus that infect the feeding sites. This results in first generation damage or second generation damage "patch lesions" which can result in 33 – 50% yield loss. In serious cases, the latter can end in cane death the following winter or spring (Gordon and Williamson, 1984).

At present in the UK, the current control strategy is to apply large amounts of organophosphorus insecticides to the base of the canes where oviposition occurs. Possible midge outbreaks can be predicted by identifying patch lesions in winter. To ensure the optimum time for spraying, growers should examine new splits on the primocane and look for the presence of eggs (Williamson and Hargreaves, 1979).

A predictive model, which estimates the emergence time of the first generation is also available to optimise pesticide use. Within the RACER study, the UK midge prediction model was tested and recalibrated at sites in Finland, Scotland, Switzerland and Italy (Barrie *et al*., 2000). Hourly and daily soil temperatures were recorded at or very near to the sites. Midge eggs were monitored using artificial splits marked on the canes. Previous research has shown that the date of emergence is dependent on the accumulated 10cm soil temperature. In the UK, where the prediction system has been running for ten years, there was a marked reduction in the number of sprays and 77% of growers reported that blight control had improved as a direct consequence of the warnings. The timing of the insecticide sprays using the prediction system reduced the danger to the bees. The RACER study indicated that local populations were thermally adapted to their local conditions and that their emergence time was linked to the availability of new splits in the canes. Further work would be needed to test this theory but this is a basis for the development of a strategy that reduces the need to use pesticide sprays against *R. theobaldi*.

Vine weevil (*Otiorhynchus sulcatus*)

The vine weevil is a destructive pest of many horticultural crops of the temperate regions. Infestations are most common in Europe and the United States with nearly

150 plant species identified as possible hosts of the vine weevil (Moorehouse *et al*., 1992). The strawberry is a very susceptible host?. Larval damage to root systems if severe, can cause yield loss and death of plants (Moorehouse *et al*., 1992). Increasing horticultural intensification at the beginning of the 1900s, saw changes in practices that favoured the weevil. These practices included the use of polythene mulches (Moorehouse *et al*., 1992). The development of the persistent organochlorine insecticides greatly decreased the numbers of *O. sulcatus* in the 1940's, but the banning of many of these pesticides has left the industry in a very vulnerable position.

There is one generation a year and the larvae *of O. sulcatus* overwinter in the soil. Most of the damage is caused by the root feeding larval stage. After pupation the adult vine weevils, which are all parthenogenetic females, emerge and begin to feed. They are active at night and hide in cracks in the soil or around the base of the leaf petioles during the day. After approximately nine feeding weeks, oviposition begins. There is some debate over where the eggs are placed (Moorehouse *et al*., 1992). Some reports suggest that the adults oviposit randomly onto the soil from the feeding site (Neiswander, (1953) and Breakey, (1959), sited in Moorehouse *et al*., 1992). Other reports suggest that the adults carefully place the eggs at sites such as the leaf vein or at the base of the stems to optimise the survival chances of the offspring (Moorehouse, (1990), cited in Moorehouse *et al*., 1993).

The use of pathogenic nematodes to control the number of weevil larvae has been considered. Nematodes such as *Steinernema* and *Heterorhabditis* (Bedding and Millar, 1981, cited in Watt, 1999) have been used successfully in protective cultivations but have not been successful under field conditions where the soil temperatures can be much lower. Another possible biological control agent is the insect parasitic fungi, *Metarhizium anisopliae* (Moorehouse *et al*., 1993) but this is unlikely ever to be used in the UK because of the high cost of registering a microbial biocontrol agent (Watt *et al*., 1999).

The use of "clean zones" in cultural control, which are protected by physical barriers could prevent the weevils spreading from an infected area (Cowles 1995, cited in Watt *et al*., 1999). Another possible method is to remove the foliage after harvest and so disrupt the weevils oviposition, due to the hot and dry atmosphere that is created (Garth and Shanks, 1978, cited in Watt *et al*., 1999).

In addition to biological and cultural methods to control the vine weevil, development of natural genetic resistance and gene transfer systems, may provide a different strategy of control. At present no natural resistance has been found in the commercial strawberry germplasm so this resistance will have to come from outside the current strawberry germplasm. Watt *et al*. (1999) reviewed the latest gene transfer research that may have the potential to provide resistance in the future.

A monitoring programme was set up in a vineyard in the USA to allow the growers to time the pesticide sprays to maximise the effect of controlling *O. sulcatus* (Phillips, 1989). Corrugated cardboard tree wraps were wrapped around the vine trunk and secured. These wraps were checked for adults every week. The adults were removed and placed in cages with nursery plants to observe when egg laying commenced. The findings showed that it was possible to determine adult emergence and when egg laying would begin. This window of 2-4 weeks would be the best time to apply pesticide around the trunk and in the soil surrounding the trunk, avoiding whole foliage application and so limiting the effect on biological control of other pest species.

Clay-coloured weevil (*Otiorhynchus singularis*)

O. singlaris is a pest of raspberries in Europe and particularly Eastern Scotland where they feed on bursting raspberry buds and developing fruiting laterals. Control of this weevil is centred around using a nocturnal application of organophosphorus insecticides to reduce the number of adult feeding in the spring, but this method is not proving successful in some areas. Research is required to start developing methods to control this pest that will reduce the amount of chemicals used.

Strawberry blossom weevil (*Anthonomus rubi*)

The blossom weevil is a major pest in the UK, particularly effecting late flowering June-bearer strawberry cultivars and everbearing types. Growers have experienced a greater problem with this pest since the push towards late season production (Cross and Easterbrook, 1998).

In April the adults begin to emerge from hibernation but the feeding by the adults is not usually harmful. The damage occurs when the adults lay their eggs in unopened flower buds and then proceed to puncture the pedicel with a series of 5-10 holes below the bud, resulting in the death of the flower.

As this insect has the potential to reduce yields, a pesticide is needed to control it. However, the pesticide used is under review and there are no known natural predators so other methods are being sought. A possible method to reduce the damage caused by this pest is to find resistant cultivars. There have been reports of cultivar differences in susceptibility to *A. rubi* (Höhn and Neuweiler1993, Popov, 1996, cited in Simpson *et al.* 2002) and also reports of a heritable basis for these differences that were independent of flowering time (Simpson *et al.*, 1997). A breeding programme at Horticulture Research International is in the process of developing late flowering June-bearer varieties that have reduced susceptibility to *A. rubi* (Simpson *et al.*, 2002).

Twospotted spider mite (*Tetranychus urticae*)

If raspberries are defoliated by this pest before September, the buds that should remain dormant until next spring may develop in the present year resulting in reduced yield the next year. Defoliated primocanes are also more susceptible to injury from frost. *T. urticae* is also a pest of other *Rubus* species.

Work in the United States by Shanks and Moore (1996), indicated that there may be resistance to *T. urticae*, which would reduce the amount of pesticides used to control this pest and in return would help maintain the populations of valuable mite predators.

There is some evidence that suggests that there is a seasonal decline in the number of spider mite on cultivated strawberries (Chaplin *et al.*, 1971, Rodriguez *et al.*, 1970, Dabrowski et al., 1971 and MacFarlane and Hepworth, 1994). This decline is probably caused by physiological changes in the plant as a result of previous mite feeding at the start of vegetative growth after flowering. MacFarlane and Hepworth (1994) determined the extent and timing of this resistance, in four major cultivars grown in Australia, in order to develop a more effective IPM program for the strawberry industry. It was observed that the mite numbers fell dramatically two weeks after the beginning of harvest, and eventually reached zero near the end of the harvest. They suggested that this could have important implications in IPM systems as the success of the predator, *P (genus required if first mention). Persimilis (Common name?),* may have been overestimated as in fact the decline was due to host plant resistance.

Blackcurrant gall mite! (*Cecidophyopsis ribis*)

C. ribis is a major pest of blackcurrant as it transmits Blackcurrant Reversion Virus. The mite itself is very damaging, inducing galling and sterility of buds and is regarded as one of the most serious pests of blackcurrant. The symptoms of black currant reversion disease are the change in appearance of the blackcurrant bush back to a wild type plant. Resistance to the gall mite has been identified in other *Ribis* species but the is still much to understand about the ecology and epidemiology of *C. ribis* and the reversion, such as the gall mites ability to transmit the virus and whether other *Cecidophyopsis* species can transmit the virus, before control strategies can be developed (Jones, 2000).

Development of a complete IPM system in soft fruit

An IPM study in the United States (LaMondia *et al*., 2002) observed the effect of rotation and intercropping on the number of strawberry pests in the plantation. Rotation of crops is a non-chemical option which can be used in an IPM system. This works by choosing an appropriate species which is not a host to the pest concerned. This will minimise the number of pests that can develop in the field and may also influence to soil and crop ecology through the competition and production of biologically active secondary plant compounds. They used two crops in rotation with the strawberries, a diploid 'Saia' oat (*Avena strogosa*) and 'Triple S' sorgho-sudangrass (*Sorghum bicolour x S. sundanense*) and showed that this suppressed pathogens, weeds and soil insects. However there were some trade-offs. If left to grow, these crops compete with the strawberry crowns and reduce vigor and yield. A major insect pest of strawberries in the United States, the larvae of various scarab beetles was kept in check during the first year of the trial. They believed that the height of the cover crops interfered with the flight of the beetles reducing the number of oviposition sites available to them. Unfortunately, the second year saw an increase in the numbers of larvae. This could have been due to a number of factors including the lack of physical barriers present as the crops were kept at a lower height and as a result the behaviour of the beetles was not effected as observed in the previous year. Another possible explanation could have been the increase in decaying organic matter as a result of the previous year rotation crop and this could have improved the survival rate of the larvae. This means that crop rotation is only a short term answer to controlling the beetle larvae, during the first year of planting (LaMondia *et al.*, 2002).

IPM systems in Apple

To make a comparison between the status of IPM development in soft fruit, the IPM development in another fruit, the apple, will be discussed.

There are many arthropod pests of apple plantations. These include: aphids, apple sucker, common green capsid, winter moth, apple sawfly, tortricids, codling moth, and fruit tree red spider mite. There has been much work done in developing IPM systems in apples in all countries. IPM development in apple has gone through the same developments as soft fruit but IPM systems in apple production have become very well established in most apple production systems. However, Prokopy (1990) and Prokopy *et al*. (1996), still believes that there is still much improve to obtain a high quality, high yielding crop. To date, all the IPM practices have been "bottom – up" strategies relying on natural ecological processes exerting their full strength. Prokopy suggests that the development and refinement of ecological practices must continue and the need to communicate ideas across all levels, from producers to consumers is essential to improve the crop. His proposal is summarised in table 4.

IPM level	**Strategies**
First - level	Development of ecologically sound multiple tactics for a single class of predator. Encourage ecological factors such as habitat structure and beneficial insects.
Second - level	Integration of multiple management strategies across all types of arthropod pests (or all types of disease pests).
Third - level	Integration of ecological agricultural tactics and strategies involving integrating of management approaches across the entire system of crop production.
Fourth - level	Blending the concerns of those having vital interest in pest management : researchers, industry, growers, consumers, environmentalists and government regulatory bodies.

Table 4. The levels of development in apple IPM. (Prokopy, 1990)

The effect of pesticide on the faunal composition, abundance, and body length of spiders in apple orchards in Massachusetts was compared using first-level IPM plots and second-level IPM plots with unsprayed plots (Wisniewska and Prokopy, 1997). In the first-level IPM plots, pesticides were applied as needed throughout August and in the second-level IPM, pesticides were only applied until early June. The study showed that the numbers of spiders were severely reduced and the body lengths were shorter in the first and second-stage IPM plots suggesting, that the use of insecticides even if confined to the beginning of the season, have a negative impact on the number of potential predators in the apple orchards.

There has been a great amount of work done on the control of a major pest of apple orchards, the European sawfly, *Hoplocampa testudinea*. This pest has a wide area of distribution being found in most area apple growing areas in the Palaearctic region between 40 and 60 degree northern latitude (Velbinger, 1939 cited in Graf *et al.*, 2001) and is also found in the eastern and western parts of the North American continent where it was introduced from Europe in the 1930's (Pyenson, 1940 cited in Owens and Prokopy, 1978).

Summary

Although Integrated Pest Management is not a new term, the techniques required in this type of agricultural system have not been developed because of a reliance on the use of pesticides. New regulations, brought about by consumer fears of pesticide residues and environmental concerns, will result in a large proportion of the active ingredients presently available being phased out over the next 8-10 years. This process has already started and growers are beginning to find it tough to manage the pests with the chemicals available.

This suggests that IPM systems, i.e., systems that use other control measures to reduce the amount of pesticides used, will become a more important part of today's agricultural systems.

This review showed that the amount of IPM research in the United States and developing countries is much further ahead of UK and the rest of Europe. Also noted, was that some crops have more IPM control strategies available than others. For example, apple production has many strategies that control a number of pests but soft fruit production has very few strategies and still relies heavily on pesticide inputs.

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