



Agriculture & Horticulture
DEVELOPMENT BOARD



Grower Summary

SF 074 (HL 0175)

Integrated pest and disease
management for high quality
raspberry production

Final year

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Project Number:	SF 074
Project Title:	Integrated pest and disease management for high quality raspberry production
Project Leader:	Professor Jerry Cross
Report:	Final Report 2011
Publication Date:	27 September 2012
Start Date:	01 April 2006
End Date:	31 March 2011
Project Cost (total project cost):	£145,000

Headline

A successful Integrated Pest and Disease Management (IPDM) programme has been developed for raspberries which will greatly reduce and possibly eliminate pesticide residues. The programme will give good results but is likely to cost on average between £25 and £45 extra per tonne to implement compared to a conventional grower management and routine pesticide based programme.

Background and expected deliverables

Raspberries are very susceptible to botrytis, powdery mildew, raspberry beetle, raspberry cane midge and aphids. Pesticides are currently relied on for control and are applied close to harvest. Intensive use of pesticides, including the organophosphate (OP) chlorpyrifos, which is used to control raspberry beetle and cane midge, is undesirable and unsustainable. Raspberry aphids, and the viruses they spread, are becoming more important. Indeed, some aphid populations have overcome the natural plant resistance.

Botrytis is the major cause of post-harvest fruit rotting and causes serious yield losses. Poor shelf-life reduces repeat buying. Retail surveillance has demonstrated that more than 50% of UK produced fruit contains fungicide residues and 22% contains chlorpyrifos residues. The major multiple retail customers are challenging raspberry producers to significantly reduce this incidence of residues.

The future registration of chlorpyrifos on raspberry is in doubt. Earlier screening trials by East Malling Research (EMR) failed to identify any alternative insecticides with significant activity for cane midge control, though in a 2009 HDC funded trial (SF 101), sprays of neonicotinoid insecticides (e.g. Calypso, Gazelle) gave good curative control of cane midge larvae in splits. Immediate loss of chlorpyrifos however would have serious adverse consequences for the UK raspberry industry as there is currently no alternative control measure for the midge.

Raspberries suffer from rain damage and, to meet the requirements of major multiple retailers, the crop now has to be grown under protection. Recent observations indicate that this increases the risk of powdery mildew infection in protected crops. Plant protection methods have not been adapted for this new growing environment, which provides opportunities to reduce reliance on pesticides.

The strong market demand to reduce, or ideally to eliminate the occurrence of residues prompted this 5-year HortLINK project which officially started in April 2006, following

considerable initial work in 2005. It aims to develop sustainable methods of integrated management of botrytis, powdery mildew, raspberry beetle, raspberry cane midge (with associated disorder 'midge blight') and aphids on protected raspberry crops. Such methods would not rely on sprays of fungicides and insecticides during flowering or fruit development so that quality fruit can be produced with minimal risk of occurrence of detectable pesticide residues at harvest.

In the first three years of the project (2006-08) individual new technologies were developed along with control methods for the major pests and diseases of raspberry which do not rely on pesticide use that is likely to lead to residues in fruits at harvest. At the end of the three years, these were combined with existing methods into a minimal residues IPDM programme which was tested in years 4 (2009) and 5 (2010) of the project. This report summarises the results of all the work which took place over the 5 years of the project.

Summary of project and main conclusions

Objective 1. Botrytis

Task 1.1. Inoculum source

Previous field observations led to formulation of the hypothesis that infection of canes arose from invasion by mycelium from the petioles of infected leaves and that only mature and old leaves are susceptible. The research results obtained did not fully support this previous hypothesis about cane infection; cane age rather than the leaf age *per se* influences leaf susceptibility with leaves on young canes less susceptible than those on old canes. On older canes, leaves of all ages, ranging from young expanding to old senescent, were equally susceptible. Furthermore, both controlled inoculation and field monitoring suggested that most cane infection resulted from the direct infection of canes by the pathogen rather than through invasion via the petioles of infected leaves although infection of cane occurs readily following wounding around the petioles.

Provided the sclerotia are wetted, or incubated in high humidity for 2 weeks, sclerotia on canes will sporulate. Although sclerotia overwintering on fruiting canes are normally considered an important source of botrytis inoculum in spring, the incidence of cane botrytis and sclerotia was very low. Sporulation of botrytis sclerotia on fruiting canes can occur from mid-May (when crops are usually at first open flower) through to at least mid-August, especially so for the Cambridge site in the trial where the crop was covered late in the spring.

In contrast, when the crop was covered very early in the spring, there appears to be no opportunity for sclerotia to be wetted and hence to initiate sporulation when temperatures rise in spring. Therefore, sclerotia overwintering on canes are not a major source of inoculum for early covered crops. Weeds and crop debris do not appear to be a main source of *Botrytis cinerea* spores for flower infection.

B. cinerea may possibly arise on canes from overwintering in the crown as well as from deposition of conidia in the air. Symptomless infection can occur in buds of floricanes visibly affected by botrytis; as most buds on such a cane were usually infected, the infection may be systemic.

Task 1.2. Environment manipulation

Botrytis cinerea causes disease on both the fruit and cane of raspberry. The incidence of latent and post-harvest fruit botrytis was examined in 19 commercial open-field and protected crops. Many samples showed a high incidence of infected fruit (>50%), even on protected crops sprayed with fungicides. Differences between open-field and protected crops, between sprayed and unsprayed crops and between two varieties (Glen Ample and Tulameen) were not statistically significant. The incidence of latent infection by *B. cinerea* in unripe fruit did not correlate with the incidence of botrytis fruit rot developing on ripe fruit.

Experiments were conducted in two commercial crops to investigate whether the removal of lateral leaves and thinning of primocanes during the flowering and fruiting period could reduce the incidence of fruit and cane infection by *B. cinerea*. Canopy manipulation resulted in considerable decreases in humidity inside the canopy at one site, where the original cane density was very high, (20 canes/m) and not at the second site where cane density was lower (10 canes/m). Canopy thinning did not significantly reduce the incidence of fruit botrytis at either site but reduced the incidence of leaf and cane infection in the dense crop. Results suggest that a significant reduction of cane infection by canopy manipulation can be realised for situations where cane density and disease pressure are high. The present studies suggest that in dense canopies in a protected crop, cane lesions are more likely to result from direct infection of canes by the pathogen, although the pathogen can readily invade wounds on canes, including de-leafing wounds.

Tasks 1.3-1.4 Individual strategies for management of Botrytis cinerea

Only urea appeared to consistently suppress sporulation of sclerotia on canes. Application of urea at 50 kg/ha did not result in any obvious sign of phytotoxicity on raspberry plants when applied in winter.

Fungicides, in particular UKA379, UKA374, Talat (tolylfluanid + fenhexamid), Signum (pyraclostrobin + boscalid), Switch (cyprodonil + fludioxonil), Scala (pyrimethanil), Amistar (azoxystrobin) and Folicur (tebuconazole,) gave the most consistent control of botrytis in post-harvest tests. None of the alternative chemicals evaluated had any effect on botrytis incidence apart from Hortiphyte Plus which showed some reduction in rotting at one pick date at the Kent site. However, further trials showed that Hortiphyte Plus applied alone did not significantly reduce botrytis incidence.

Task 1.3.5. Management of fruit botrytis by cooling

The incidence of botrytis at harvest was very low, but rapidly developed in fruit samples post-harvest, suggesting that post-harvest cool chain treatments may delay the onset of fungal rotting. Latent *B. cinerea* occurred in fruit from all crops at significant levels, with the incidence varying greatly between picks. The outdoor untreated crop had the highest incidence; spraying protected crops only led to a very small reduction in the incidence of latent infection. Most importantly, there was virtually no fruit with visual grey mould at harvest; fungal rots (including those by *B. cinerea*) usually only appear after being stored for 8 days.

Compared with ambient storage, initial cool storage of the fruit significantly delayed the onset of fungal rotting. Furthermore, these results suggested that the rapid cooling (within 1-h of the pick) is critically important to delay the onset of fruit rotting.

Objective 2. Raspberry Beetle

Task 2.1. Conduct field experiments to develop monitoring methods

On station experiments (Years 1 and 2) at SCRI were used to test different designs of the trap and lure. The non-sticky impact (funnel) traps had clear advantages over the original Swiss designed white sticky traps. The latter were difficult to handle, needed changing twice a week, caught many more non-target insects (becoming saturated quickly) and were more expensive in the long term (disposable and labour intensive).

Task 2.2. Optimise lure for control

On station trials were conducted at SCRI in Year 1, testing single (compound B) versus double (A+B, A+A, B+B) attractants. In the UK, attractant B was found to suffice, enhancing RB catches of just the visual component of the trap (white, non UV reflectant cross vanes) by

x10-x50 times. In areas of very high pest pressure (e.g. organic smallholdings in Norway and alpine Switzerland) some advantage was seen in adding the second attractant (A).

Task 2.3. Choose appropriate control approach and optimise device

In discussion with ADAS, Agrisense, Suterra, MRS Ltd and registration agencies (HSE, PSD) it was agreed that it was not currently economical to register the RB trap and lure for 'lure and kill'. Given this consensus, it was agreed that the most appropriate approach to control for the main U.K. raspberry growing sector was to choose precision monitoring (i.e. detection of 'hot spots') within the crop, using combined action thresholds (currently 5/trap/week when used at a rate of 50/ha) for spraying approved insecticides.

In other countries where organic production is more profitable (e.g. Norway), collaborative trials were run by Bioforsk (Dr N. Trandem). These showed that the trap and lure system at 50/ha were insufficient to reduce fruit damage to low (UK) levels, although 40-50% reduction in fruit damage was achieved over 2-3 years. Instead, the control approach for these Norwegian organic growers was modified so that extra traps were placed outside the cropped area (nearby woodlands with wild hosts) so that more RB were caught before they entered the crop and interception fences could be erected to interfere with RB flight paths. The bee excluder mesh was designed by SCRI and Agrisense Ltd half way through the HortLINK project. This proved to be very effective in stopping bees from entering the traps.

Trials in the UK, France (Ctifl) and Norway (Bioforsk) showed that the traps were most effective when deployed 4-6 weeks before first flowering of the crop. However, additional trials in Switzerland and Norway also showed continued catches throughout the season, with a second RB flight peak in late July-early August (alpine Switzerland, 2 sites). Again, the traps provided a route to regionally fine-tuned monitoring and control strategies. This requires more knowledge transfer and training of growers in IPDM, so is a medium (2+ years) to long term strategy. In both Scotland and Norway, growers became familiar and confident with the traps and lures in 1-2 years of on farm trials and had customised deployment strategies for their own fields within 2-3 years.

Task 2.4. Deployment strategies

In the on-farm trials in the UK, complemented by additional on-farm trials in Norway and Switzerland, a lattice design (within crop) was compared with perimeter trapping, both at 50 traps/ha. In several on farm trials over 2-3 years the lattice deployment design was shown to be more effective than perimeter trapping. This in part reflects the finding during HL0175 that

at several UK study sites, RB occurs mainly as resident populations within tunnels, with few immigrating from surrounding vegetation (hedgerows, wild bramble etc) outside the crop. The opposite was observed in parts of Norway, where huge reservoirs of RB were detected in surrounding woodlands using the traps; these flew into organic smallholdings over a more extended period than in the UK.

Thus, the precision monitoring system enabled optimal deployment strategies to be designed and deployed for differing geographical, climatic and agronomic conditions. It is recommended that the traps are used for at least a year at each site to monitor pest movement before optimising the spatial and temporal deployment of the traps for subsequent years. Besides raspberry, the trap and lure system was shown to be very effective when deployed in blackberry crops (UK and Switzerland).

Given the high cost of investing in traps (which should last for 5+ years, with annual investment in new lures), some UK growers may prefer to monitor at lower precision, using 5-10 traps/ha rather than 50/ha (the current recommendation for precision monitoring). This has the advantages of a) reducing initial grower costs, b) enabling growers to become familiar with the IPDM technology before making a bigger investment, c) growers can move traps around their farms, allowing them to monitor crops with differing flowering and fruiting periods, d) they can also monitor the efficacy of applied insecticides (post application monitoring) in different parts of the farm easily (the traps are easily moved between sites).

Objective 3: Semiochemical-based systems of managing cane midge

Task 3.1. Develop effective sex pheromone lure and trap for raspberry cane midge males

The female sex pheromone of the raspberry cane midge (*Resseliella theobaldi*) (Cecidomyiidae) was identified as (S)-2-acetoxy-5-undecanone and the synthetic compound was shown to be highly attractive to male midges in the field. The R-enantiomer was unattractive but the racemic mixture containing equal amounts of the R- and S-enantiomers was as attractive as the S-enantiomer. This is an important result as the racemic material is much easier and cheaper to synthesise than either of the pure enantiomers. In field trapping trials, increasing the loading of pheromone in the lure gave increased catches of midges up to 1 mg, but further increase in loading decreased catches, indicating an optimum loading of 0.1 mg – 1 mg per rubber septum lure. Colour of the trap did not have any effect on catches of midges, but greater numbers of non-target arthropods were caught in white and blue traps. Red traps are recommended for practical use. The

height of the trap above the ground had a very significant effect on catches of midges. Traps positioned on the ground caught most midges with catches dropping dramatically at higher positions. In practice it is not feasible to place traps on the ground for long periods and a trap height of 0.5 m is recommended.

Task 3.2. Investigate use of sex pheromone trap for monitoring raspberry cane midge males

A ring test was conducted by fruit entomologists in nine EU countries and Russia in 2006 and a strong linear relationship between sex pheromone trap catches of raspberry cane midge and numbers of larvae found subsequently in splits in raspberry canes was established. The relationship has not been used directly for setting trap thresholds because the relationship between larval infestations and crop damage has not been established. However, a low 'nominal threshold of 30 midges per trap per week was set for timing of sprays of insecticide.

Task 3.3. Investigation of attraction of raspberry cane midge to volatiles from wounded raspberry primocanes

Mated females of raspberry cane midge are known to be strongly attracted to odours from recently split raspberry primocanes. Fresh splits are preferred over old ones suggesting the attraction is due, at least in part, to volatile chemicals produced. Using solid-phase microextraction (SPME) to sample the volatiles *in situ* it was shown that a characteristic suite of chemicals was produced after splitting, and these were similar for five varieties of raspberry. The components were identified and the 18 most abundant were selected for further study, including six produced by intact stems and 12 produced after splitting. Of these, four elicited EAG responses from the antenna of a female *R. theobaldi* midge, including three from the group produced only after splitting. For field studies exclusion of the least abundant compounds gave a reduced set of 13 compounds and it was shown that dispensing four of these from a polyethylene vial and the other nine from a polyethylene sachet gave a reasonable approximation to the blend observed from raspberry canes after splitting.

Field trapping studies were carried out in Hungary and the UK during 2009 and 2010 and these have given variable results. In general, numbers of female *R. theobaldi* trapped were very low, although significant numbers were caught in the test in Hungary during 2010. At two sites in Hungary and one in the UK during 2009, more males were caught in traps baited with the synthetic cane volatiles than in unbaited traps. At one of these sites numbers caught with the cane volatiles were similar to those caught with the sex pheromone. At two other sites in the UK, numbers of male *R. theobaldi* caught with the cane volatiles were significantly less than those caught in unbaited traps. The former three sites were all open-

field while the latter two were covered and it was thought that this factor might be affecting the performance of the synthetic lures. However, these results could not be repeated in 2010. Numbers of male *R. theobaldi* caught in traps baited with the total volatile mixture were not greater than those caught in unbaited traps in either Hungary or the UK, although a reduced blend of the four most volatile compounds showed some attraction to males in the UK. Although considerable progress has been made, further work in both laboratory and field is required. The development of lures attractive to gravid female *R. theobaldi* would provide powerful new tools for monitoring and control of this pest.

Task 3.4. Develop effective host volatile lure and trap for monitoring raspberry cane midge females

Preliminary work towards this objective is described above in section 3.3. As a female attractant was not developed no other work was done on this sub-objective.

Task 3.5. Investigate use of the host plant volatile lure and trap system for monitoring

As an attractive host volatile lure was not fully developed (still at prototype stage) in 3.3 and 3.4. above, no further work was done on this sub-objective other than testing different blends, release rates and dispenser designs in small scale experiments (UK and Hungary).

Task 3.6. Investigate use of the sex pheromone, initially alone, then in conjunction with the host volatile attractant for control by disruption, mass trapping or lure and kill

Between 2006 and 2010, the efficacies of 5 Mating Disruption (MD), 2 Attract and Kill (A&K) and 1 Mass Trapping (MT) raspberry cane midge sex pheromone treatments were evaluated in large-scale, unreplicated field experiments for control of raspberry cane midge in commercial raspberry plantations in SE and E England in comparison with untreated controls. The treatments evaluated comprised a wide range of dispenser/device types and dose rates of pheromone per ha, the upper dose limit being restricted to 10 g per ha by the terms of the experimental permit for the work. The efficacy of the treatments was evaluated in terms of how effectively they suppressed catches of male midges in single standard sex pheromone traps deployed in the centres of each plot, and in terms of the degree to which they reduced larval infestations in artificial splits in the primocanes through the season.

None of the 8 pheromone treatments performed consistently well, and none appeared satisfactory for control in commercial plantations. The sex pheromone trap catch was suppressed compared to its untreated control in all but one of the 21 different ~ 1 ha plot trials in which the 8 different treatments were evaluated, but good control of larvae only occurred in those trials where a high (>90%) or very high (>98%) degree of trap shut down resulted,

though not necessarily so as poor control resulted in two trials where there was a very high degree of trap shut down. One of the main problems encountered with the different formulations was sustaining an adequate release of pheromone through the season.

Of the treatments evaluated, a treatment with 5000 0.4 g dollops of SPLAT (Specialized Pheromone & Lure Application Technology) containing 0.5% sex pheromone racemate per ha (10 g pheromone racemate/ha) was the best for ease of application and steady release rate and the most promising for further development. SPLAT is a proprietary (ISCA technologies, CA, USA) wax emulsion formulation used to control the release of semiochemicals. This treatment gave good control of first generation larvae in one trial in 2010, though control broke down for the second generation despite a second application. The SPLAT formulation and method of use (size and number of dollops) allows the release rate to be adjusted to a considerable extent and the amorphous and flowable quality of this formulation means that its application can be mechanized making application of large numbers of dollops per ha economically feasible. Further trials exploring a range of pheromone doses in SPLAT dollops of varying size and with higher numbers of dollops per ha are needed to improve the treatment to obtain a reliable and acceptable degree of efficacy.

Objective 4. Powdery mildew

In Year 2, the consortium decided to omit the powdery mildew from this project. Instead the work focused more on *B. cinerea* for the following reasons:

1. Powdery mildew failed to establish in crop despite repeated efforts of artificial inoculation by EMR and ADAS
2. Noticeable amounts of powdery mildew were not observed in commercial crops.

Thus, for powdery mildew, research activities were only carried out with meaningful results on the genetic differences between powdery mildews on raspberry and strawberry. Both diseases are believed to be caused by the same fungal species (*P. aphanis*). However, this paper shows that the mildews on these two hosts are genetically distinct. Sequencing the ITS region of a number of selected samples from the two fungi clearly indicates that these two fungi are genetically different.

Objective 5. Aphids

The aphid species that are significant pests of tree and bush fruit crops in Europe are mostly host-alternating. They spend autumn, through winter, spring and early summer on their winter

host, typically woody tree or bush fruit species. In mid summer they migrate to herbaceous hosts. In the autumn, there is a return migration to the winter woody host by males and pre-sexual females (gynoparae), the latter producing sexual females (oviparae) which mate with the males and lay overwintering eggs on the bark. The aim of autumn applications of aphicides is to control a very high proportion of the gynoparae, males and oviparae before overwintering eggs are laid. Logically, the best time to treat is immediately before egg-laying commences, catching the maximum proportion of the migrants i.e. when the autumn migration of gynoparae is near its end and at the start of the male migration, because oviparae cannot lay eggs unless they are mated. There is normally a 2-3 week delay between the migration of gynoparae and that of the males.

Large scale field trials were done in commercial raspberry plantations in Kent to test different timings of autumn sprays of pirimicarb (Phantom), thiacloprid (Calypso) and pymetrozine (Plenum) for the control of small raspberry aphid (*Aphis idaei*) and large raspberry aphid (*Amphorophora idaei*). Single sprays were applied to replicate plots of Glen Ample in the autumns of 2005, 2006, 2007 and 2008. Populations of aphids were assessed in the winter (numbers of eggs) and spring (numbers of adults and nymphs). Calypso sprays greatly reduced populations of large raspberry aphids that developed the following spring by up to 99% in most years. Aphox, Phantom and Plenum gave less consistent results. Early – mid October was the optimum time for a single application of Calypso to reduce spring populations of large raspberry aphid and should be considered as part of an Integrated Pest Management programme.

Objective 6. IPDM programme

Based on the research conducted in the first 3 years of the project, a Minimal Pesticide Residue Integrated Pest and Disease Management (IPDM) programme was devised and was tested and refined in years 4 (2009) and 5 (2010) of the project. The key features of this programme were:

1. Good crop hygiene and cane management together with rapid fruit cooling and high quality cool chain marketing to avoid the need for fungicide sprays for botrytis during flowering and fruiting.
2. Application of 1-2 sprays of a powdery mildew fungicide in the spring as soon as the tunnel was covered; then subsequent sprays of potassium bicarbonate for eradication of powdery mildew if the disease is observed.

3. Use of 50+ Agrisense raspberry beetle host volatile funnel traps with white cross vanes/ha. Sprays of Calypso are used only where trap catches exceed thresholds, indicating where local treatment is necessary (e.g. hot spots within tunnels, whole tunnels or field-grown crops in adjacent fields and whole farm level). Note that no Calypso sprays were applied in the trial in Kent (2009), even though the traps catch threshold was greatly exceeded.
4. Application of a sex pheromone attract and kill treatment (SPLAT) for raspberry cane midge.
5. Removal of spent floriculture soon after harvest in August.
6. Application of post-harvest fungicide sprays to control cane diseases on new spawn, starting in August.
7. Application of an autumn spray of thiacloprid (Calypso) for aphid control (possibly supplemented with introductions of predators and parasites for biocontrol in summer).

The IPDM programme was implemented by growers in large (~ 1 ha) plots at Hugh Lowe Farms, Mereworth, Kent and Sunclose farms, Cambridgeshire. Yields of waste and marketable fruit, the incidence of pest and disease damage, shelf life and the incidence of pesticide residues were assessed in the IPDM managed plots in comparison with a similar plot where the growers standard pest and disease management programme was applied.

Yields and quality

The IPDM programme gave similar yields and quality to the conventional growers programme in both years of the project. The IPDM pest and disease control methods gave a high standard of control of the main pests and diseases of raspberry.

Residues

At the Cambridgeshire site in 2009, the IPDM programme had no residues of the botrytis fungicide fenhexamid compared to 0.02 mg/kg for the grower standard. Residues of pyrimethanil were reduced by 80-95%. In 2010 at this site, residues of azoxystrobin were zero on the IPDM treated plot compared to trace levels on the grower's plots. However,

trace levels of cyprodinil and fludioxinil occurred in the IPDM treated plots whereas these fungicides were not detected in the growers plot. At the Kent site, trace residues of pyrimethanil on the grower's plot were not detected in the IPDM plot. Thus the IPDM programme greatly reduces residues but pre-flowering sprays of fungicides may still result in trace residues. It is anticipated that insecticide residues would be eliminated.

Pesticide use

We have estimated that on average, numbers of sprays would reduce from 9 per season for a typical growers pest and disease control programme to 5 sprays for the IPDM, a reduction of 44% (Table 6.2.13).

Variable costs of the IPDM versus the grower's standard programme

We have estimated that the IPDM programme developed will cost growers approximately £300-540 more per ha to implement than a typical routine chemical control programme. The major increased costs are due to labour required for removing debris from the tunnel twice per year to improve hygiene and the costs of raspberry beetle control using the Agrisense raspberry beetle monitoring traps. These increased costs are partially offset by the savings in pesticides. Assuming an average yield of 12 t/ha, then the increased cost is about £25-45/tonne.

Financial benefits

In 2009, 16,000 tonnes of raspberries, worth £111m were produced from 1,757 ha grown in Britain. The UK fresh market is under-supplied outside of the main season. New varieties are now being utilised to spread the cropping season and production has increased, by 45% over the last decade, and continues to do so. Surveillance of pesticide residues in soft fruit identifies raspberries as having a high occurrence of detectable residues. For example, the 2003 ACP survey found 50% of imported raspberries and 75% of home-grown raspberries had detectable residues. This greatly damages the consumer acceptability of raspberries and their image as a healthy food.

Effects of the IPDM programme on yield and quality, pesticide use and costs

The large scale grower trials in the final years of this project indicated that the yield and quality expected from the IPDM programme are the same as those from the grower's standard programme, i.e. both programmes give good control of the range of pests and diseases on raspberry. It has been estimated that the IPDM programme developed will cost growers approximately £300-540 more per ha to implement than routine chemical control programmes, depending on the extent to which their cane management practices, which vary

considerably, have to be improved. The major increased costs are due to labour required for improved cane management and removing debris from the tunnel to improve hygiene and the costs of raspberry beetle control using the Agrisense raspberry beetle monitoring traps. Assuming an average yield of 12 t /ha, then the increased cost is about £25-45/tonne.

Benefits of greatly reducing pesticide residues and pesticide dependence

The high incidence of pesticide residues on conventionally produced raspberries damages the consumer acceptability of raspberries and their image as a healthy food. This work has demonstrated that residues can be greatly reduced and if pre-blossom fungicide sprays were reduced, they could probably be eliminated completely. This is clearly a valuable benefit, which is hard to quantify, but is likely to cost £25-45/tonne.

Action points for growers

An HDC factsheet (13/11 – Residue reduction in commercial raspberry crops) has been prepared to give detailed grower recommendations arising from this project. The recommendations refer to summer-fruiting protected crops but equally will apply to double-fruited primocane crops (i.e. those that crop in the spring and the autumn). The key features of the minimal residues IPDM programme which growers should implement are listed below. The guidelines must be considered alongside features known to influence pest and disease risk. These include site, varietal susceptibility, age of plantation, duration of tunnel covering, tunnel height, number of rows per tunnel and crop management practices.

Fruit Botrytis

- Cover crops at least 2 weeks before flowering (ideally before spawn emergence), to keep canes dry and reduce germination of *Botrytis sclerotia*.
- On protected crops, do not apply sprays of fungicides for Botrytis during flowering and fruit development. These are of little benefit and as good or better control of Botrytis can be achieved by good crop hygiene and cane management to ensure the canopy does not become dense, so allowing good air circulation in the crop (see cane diseases, below).
- Ensure rapid cooling of fruit to 1-2 °C immediately at harvest, followed by cool storage at 3-4°C (but note that other fruit rots may not be fully controlled).

Powdery mildew

- On varieties susceptible to powdery mildew (e.g. Glen Ample), apply 1-2 preventative sprays of a powdery mildew fungicide in the spring as soon as the tunnel is covered, then subsequently apply sprays of potassium bicarbonate for eradication of powdery mildew if the disease is observed.
- Crops covered for a long period, in low tunnels, or also covered with fleece, are more at risk of mildew due to reduced air movement.

Cane diseases (Botrytis, cane blight, spur blight and cane spot)

- Where possible cut out and remove all spent floricanes from the tunnel within 2-3 weeks of final harvest. Take care to minimise damage to primocanes by cutting the floricanes into sections prior to removal.
- Machinery exists in other industries to collect prunings, chop and dispose of them. Such machines could be investigated for use in raspberry crops. Where cane debris is left in the tunnel, pull it into the centre of alleyways and chop it thoroughly to speed decay.
- Apply a programme of 2-3 post-harvest fungicide sprays to control cane diseases on new spawn, starting from soon after removal of cladding and old floricanes.
- Work elsewhere suggests that cane blight is becoming more important due to the way crops are now grown; when tunnel covers are removed at the end of harvest the soft canes are susceptible. Therefore consider a cane blight protectant spray in the autumn.
- In the spring, a cane disease spray is less likely to be required for crops covered early. However, consider applying a spray treatment to canes (e.g. for cane spot) where tunnels are covered late. Where there are no tunnel gutters, leg rows are more at risk of cane diseases due to the greater water splash.
- In late autumn, after leaf fall, make a final check and remove diseased and damaged primocanes at or just before the final selection for tying in.

Raspberry beetle

- When planting a new raspberry plantation, where possible, avoid planting near wild blackberry, wild raspberry, hawthorn and other raspberry beetle hosts.
- Around 3-4 weeks before flowering, deploy 50+ Agrisense raspberry beetle host volatile funnel traps with white cross vanes per ha, in a regular grid through each plantation. Deploy additional traps near any remaining wild sources of raspberry beetle.
- If >5 beetles have been caught in any trap by the start of flowering, apply a spray of thiacloprid (e.g. Calypso) locally to those tunnels where the threshold has been exceeded. Insecticide treatment may be unnecessary, or may only be required in hot spots or at the edges of the crop.

Raspberry cane midge

- For varieties susceptible to cane midge, deploy two sex pheromone monitoring traps in each field in early spring (March in early protected crops, early April outdoors) and monitor weekly.
- Apply a spray of chlorpyrifos directed to the base of the primocane a few days after a threshold catch of 30 midges per traps is exceeded.

Aphids

- Apply a spray of thiacloprid (Calypso) or another suitable aphicide in early October for aphid control.
- Make a programme of introductions of predators and parasites for biocontrol in spring and summer to prevent aphid attacks, as advised by biocontrol suppliers.