Eliminating Reportable Pesticide Residues from Apples

J. V. Cross and A. M. Berrie

East Malling Research, New road, East Malling, Kent ME19 6BJ

jerry.cross@emr.ac.uk, angela.berrie@emr.ac.uk

ABSTRACT

Apples have traditionally been treated intensively with pesticides. Pesticide residues surveillance showed that in 2003 >70% contained residues above reporting limits. Several important retailers in the UK are asking their suppliers to strive towards elimination of pesticide residues from fresh produce including apples, to maintain and improve consumer trust. General approaches to reducing the occurrence of residues are discussed, including increasing harvest intervals and alternative control approaches. A new ‘zero residue’ Integrated Pest and Disease Management (IPDM) programme for apple, developed at East Malling Research, where conventional pesticides are not used during fruit development, is described and results of a 6 year experiment at East Malling to evaluate the strategy are reported together with the results of grower trials. The zero residues IPDM programme has been highly successful even on the most pest and disease prone varieties.

Keywords: *Venturia inequalis*, *Podosphaeria leuchotricha*, scab, mildew, UK

1. INTRODUCTION

Apple varieties grown in the UK are highly susceptible to a wide range of damaging pests and diseases. Adequate yields of fruit of acceptable quality cannot be produced and the crops cannot be grown profitably unless these pests and diseases are efficiently controlled. Efficient weed control is also vital. The UK apple industry relies on pesticides for these purposes. With current methods of crop protection for apples, foliar pesticide applications for pest and disease control are often made in summer during fruit development and sometimes close to harvest. Furthermore, in the past it has been common practice to drench apple fruits in fungicides and/or an antioxidant post harvest to control post harvest rots and the physiological disorder superficial scald. Use of pesticides in this way inevitably gives rise to detectable levels of pesticide residues in a high proportion of fruit and many samples contain multiple residues. Despite the intensive use of pesticides, residue levels do not exceed Maximum Residue Levels (MRLs) if Good Agricultural Practice (GAP) is adhered to.

Unfortunately, pesticides are widely regarded as highly undesirable by consumers and hence the market and there is an ongoing negative media campaign against them, fuelled by Non Government Organisations. The media firmly have pesticides in their sights. The government’s policy of ‘naming and shaming’ has significantly raised the temperature. The concept of Maximum Residue Levels is often misunderstood. They are generally regarded as safety limits whereas in fact they are the maximum levels likely if Good Agricultural Practice is adhered to. Though public opinion is often poorly informed and the adverse consequences of pesticide use in fruit often unfounded or exaggerated, it is difficult to change public opinion against such media campaigns. However, market and consumer concerns do need to be addressed. Multiple retailers have identified the occurrence of pesticide residues as being one of the prime concerns of consumers about fresh produce. For them, consumer trust is of prime importance and pesticide residues are considered to undermine that trust. Leading multiple retailers have decided to pursue a policy of eliminating residues from their produce. They are challenging the UK apple industry to meet these concerns and develop production protocols, which will greatly reduce, ideally eliminate, the occurrence of residues above reporting limits.

Thus, pesticides present a difficult dilemma to the UK apple industry. They are essential to production but using them is against the wishes of the market and consumers. They want it both ways, the very best quality at the low prices but without pesticide use and do not understand the complex issues involved. The pressure is all passed back down to the producer. This problem is not unique to top fruit production, but it is a difficult problem in top fruit requiring radical change. Fortunately, it is not as challenging as eliminating residues from other produce where alternatives to pesticides for major pest and disease problems do not exist and where not using pesticides would result in a major loss in quality. In this paper, firstly we report on which pesticide residues occur in harvested fruit giving the reasons they are used (See also Berrie and Cross, 2005; Cross and Berrie, 2005; Berrie and Cross, 2006). Then we list the generic approaches to reducing the incidence of pesticide residues, then we briefly outline the East Malling zero residues apple production strategy and summary results of a 6 year research project funded by Defra and HDC to evaluate and refine the strategy both experimentally and in commercial practice.

UK government agencies (PSD, CSL) conduct regular retail surveillance of pesticide residues in samples of fresh produce. The results are published quarterly on the web. Apples, an important dietary constituent, are surveyed every year. In 2003, 301 apple samples, 82 UK produced and 219 imported, were taken from retail outlets and analysed for residues of 109 pesticides. 71% of UK produced and 71% of imported samples contained residues above the reporting limits (5.3% had two residues, 5.0% had 3 residues, 3% had 4 residues and 1% had 5 residues). There were 3 MRL exceedences, all in imported produce. A number of pesticides are found at levels above the accepted reporting limits (RL) in UK produced fruit (Table 1). There is a high level of unit-to-unit variability in pesticide residues, the extent of which appears to be determined at the time of pesticide application (Hill and Reynolds, 2002). Absence of a mean residue above the reporting limit in a bulk sample does not necessarily mean that the residue is below the reporting limit on all individual apples. Amounts below the reporting limit are regarded as zero, even though trace amounts might be present which could be measured by a more sensitive method of analysis than the standard methods. The results for UK produced fruit showed a substantive reduction in the incidence of residues from post harvest treatments to fruit compared to earlier surveys, but an increase in the incidence of chlorpyrifos residues.

1.1 General Approaches to Reducing the Occurrence of Pesticide Residues

There are a number of well known generic approaches to reducing pesticide residues. The most important are 1) Grow resistant varieties; 2) Use non chemical control methods, especially cultural, biological and biotechnological methods, wherever possible. More attention needs to be devoted to developing and using new biopesticide products which do not leave pesticide residues; 3) Avoid use of pesticides except where absolutely necessary. This is done by frequent crop monitoring and risk forecasting; 4) Use products more intensively earlier or later in the season (e.g. pre-flowering or post fruiting to minimise problems during fruit development and fruiting); 5) Use shorter persistence products; 6) Use products that have a high reporting limit relative to their dose. Reduce the dose of applications closer to harvest; 7) Increase the harvest interval (see below); 8) By training, improve knowledge and expertise of all those involved in decision making (see below).

Table 1. Occurrence of pesticide residues above reporting limits in 2003 government surveillance of UK produced apples in 2003

Pesticide	Target	Maximum Residue Level (mg/kg)	Reporting Limit (mg/kg)	% samples > Reporting Limit
bupirimate	mildew	no MRL	0.05	1
captan	scab	3	0.05	12
carbendazim	post harvest rots/canker†	2	0.05	15
chlorpyrifos	caterpillar, aphid etc	0.5	0.02	48
diphenylamine	scald post harvest	5	0.05	6
dithiocarbamates	post harvest rots†/canker	3	0.1	1
metalaxyl	post harvest rots	1	0.05	5
myclobutanil	mildew, scab	0.5	0.05	1
penconazole	mildew, scab	0.2	0.05	1
pirimicarb	aphids	1	0.02	4
tolylfluanid	scab/post harvest rots†	5	0.05	1

† as pre-harvest sprays

The mandatory harvest intervals on pesticide labels are designed to ensure that pesticide residue levels do not exceed Maximum Residue Levels. Longer harvest intervals would be required to guarantee residue levels below the reporting limits. The extent to which the harvest interval of each pesticide product needs to be increased needs to be determined scientifically if possible, based on properly conducted residue decline studies. Residue data is normally kept confidential by parent companies and was not gathered with the intention of determining zero residue intervals. One of the main difficulties with determining harvest intervals for zero residues is that due to variation in seasonal weather, harvest intervals that ensure no residues in one year may not do so in other years. As a starting point, parent agrochemical companies need to give guidance on harvest intervals that minimise the incidence of residues above reporting limits. Attendant efficacy data also needs to be considered, as substantially increasing harvest intervals may have negative consequences for the efficacy of control of the target pest or disease. Examination and statistical analysis of the data may enable the extent to which intervals can be/need to be increased. Conduct of further studies is likely to be prohibitively expensive. Another approach now being adopted by cooperatives is to try to tie in the occurrence of residues data from their routine residue monitoring programme with last application dates from their growers spray programmes to determine what harvest intervals lead to detectable residues. This is a less satisfactory approach. If the fruit industry is not given clear guidance by agrochemical companies, then there is a danger that arbitrary increases could be instigated and particular pesticides de-listed.

2. THE EAST MALLING RESEARCH ZERO RESIDUES INTEGRATED PEST AND DISEASE MANAGEMENT PROGRAMME FOR APPLES

Prior to our work, there are very few reports in the literature of concerted research efforts focussed primarily on the development of pest and disease management programmes to eliminate reportable residues from apple, or from other fresh produce for that matter. Investigations by Jones *et al.* (1993) reduced but did not eliminate residues. In 2001 a 6 year study, funded for the first 3 years by DEFRA alone and subsequently by Defra, the HDC and World Wide Fruit, was established to investigate the feasibility of developing a zero pesticide residue system for apples. A large scale randomised block field experiment was established in Wiseman orchard at East Malling Research which had 12 existing established plots, 6 of disease-susceptible apple varieties (Cox, Gala, Fiesta) and 6 of scab-resistant apples (Saturn, Ahra, Ecolette). The variety Discovery occurs in all plots as an internal standard. Each plot consisted of 144 trees on M9 rootstock and was separated from adjacent plots by alder windbreaks. In these plots the pest and disease control achieved following a routine conventional pesticide programme is being compared to that achieved following a 'zero residue' management system. Untreated plots of disease-susceptible and resistant varieties were included (Table 2).

Table 2. Treatments in the zero residue experiment in Wiseman orchard, East Malling Research

Treat name	Programme	Management
Susceptible variety plots: Cox, Gala, Fiesta, Discovery		
U-S	Untreated	None
C-S	Conventional	Routine pesticides. Captan (28 & 14 days pre-harvest) for storage rot control
Z-S	Zero residue	Managed pesticides early and after harvest. Biocontrol during fruit development. Rot risk, selective picking, inoculum removal for storage rot control
Resistant variety plots: Saturn, Ahra, Ecolette, Discovery		
U-R	Untreated	None
C-R	Conventional	Routine insecticides and mildewicides. Reduced scab fungicide programme. Captan (28 & 14 days pre-harvest) for storage rot control
Z-R	Zero residue	Managed pesticides early and after harvest. Biocontrol during fruit development. Rot risk, selective picking, inoculum removal for storage rot control.

The zero pesticide residue management strategy is based on the use of conventional pesticides (excluding organophosphorus (OP) insecticides) up to petal fall and after harvest, but during the fruit development period to rely on biocontrol for dealing with pests and diseases. The key features are:

- Integrated pest and disease management (IPDM) from bud burst to petal fall based on conventional pesticides (thiacloprid, fenoxycarb, diflubenzuron, methoxyfenozide) but excluding organophosphate insecticides. Management of scab and mildew using ADEM disease risk forecasting model to optimise timing and dose of fungicides (Berrie and Xu, 2003).
- Use of biocontrol agents (*Bacillus thuringiensis* (Bt) or codling moth granulovirus) for pest control from petal fall to harvest.
- No conventional fungicides for disease control post petal fall except for reduced dose sulphur for mildew control. Frequent assessment of secondary mildew to determine dose of sulphur to be applied.
- Cultural control. Removal of primary mildew, cankered shoots and brown rot.
- Rot risk assessment to determine likely rot problems in the orchard (Full details in Defra Best Practice Guide for apples (Cross and Berrie, 2001)).
- Cultural control and selective picking to reduce / control rot problems in store. Only sound fruit (to avoid brown rot) and fruit above knee height (to avoid *Phytophthora* rot) picked for storage (Berrie, 2000).
- During the post harvest / dormant period, a DMI (e.g. mycolbutanil) fungicide applied for late mildew and scab control, urea for leaf rotting and scab control, copper sprays for canker control at leaf fall and copper pre budburst for overwintering scab.
- Post harvest application of an aphicide for control of rosy apple aphid.

Differences in pesticide use for the different treatments are illustrated in Tables 3 and 4 for fungicides and insecticides, respectively. In all years to date the zero residues programme has reduced fungicide costs but increased insecticide costs.

Table 3. Number of fungicide active ingredient applications for disease control in 2002 and their total cost. Note two fungicides were applied in many spray rounds

Fungicide	Conventional		Zero residues	
	Susceptible	Resistant	Susceptible	Resistant
Early copper	0	0	1	1
Fungicides bud-burst-petal fall	10	6	12	8
Fungicides petal fall-harvest	16	11	0	0
Sulphur petal fall-harvest	0	0	9	9
Post harvest fungicides	0	0	2	2
Leaf fall urea	0	0	1	1
Total cost (£/ha)	384	304	262	217

Table 4. Spray programmes applied for pest control in 2003 and their total cost

Date (2003)	Growth stage	Conventional	Zero residue
16 Apr	Pink bud	thiacloprid +methoxyfenozide	thiacloprid +methoxyfenozide
17 May	Petal fall	thiacloprid +methoxyfenozide	thiacloprid +methoxyfenozide
14 Jun	Fruitlet	chlorpyrifos	*Bacillus thuringiensis*
14 Aug	Pre-harvest	chlorpyrifos	*Bacillus thuringiensis*
30 Sep	Post harvest	-	pirimicarb
24 Oct	Post harvest	-	pirimicarb
Total cost/ha		180	339

3. RESULTS

Scab control has been as good and often better in the zero residue plots than in the conventional plots, even on Gala, a variety which is exceptionally scab susceptible and including in 2002 and 2004, when scab risk was high (Table 5). This also demonstrates that the reduced scab programme, now used on the managed plots for four seasons, does not result in a build up of scab inoculum.

Table 5. Incidence of scab on the highly susceptible variety Gala

Treatment	2001	2002	2003	2004	2005	2006
% shoots infected in July						
Untreated	90.0	100	100	100	100	100
Conventional	2.5	7.5	0	5.0	12.5	25.0
Zero Residues	0	0	0	0	0	22.5
% fruits infected at harvest						
Untreated	72	98	51	89	70.0	92.4
Conventional	0.5	5.6	0.3	2.4	1.2	6.2
Zero Residues	1.0	2.7	0.3	0.1	0	5.8

Mildew control in the zero residue plots was also similar to that in the routine treated plots, and did not exceed 20% of shoots mildewed (Table 6). The primary mildew in managed plots at the start of 2002, 2003 and 2004 was negligible, indicating that the system was not resulting in a build up of primary mildew. Primary mildew incidence was high at the outset of the experiment on the variety Ahra in one of the Zero residue management plots as prior to 2001 this plot had been untreated. However, the zero residue management system reduced the incidence of primary mildew sharply in 2001 and to zero by 2003 and 2004.

Table 6. Incidence of mildew on the highly mildew susceptible varieties Cox and Ahra

Treatment	Variety	2001	2002	2003	2004	2005	2006
% Blossoms infected with primary mildew							
Untreat-Suscept	Cox	2.3	0	3.5	1.8	2.7	6.5
Untreat-Resist	Ahra	8.4	3.3	13.5	26.9	16.1	38.3
Conv-Suscept	Cox	0	0	0	0	0	0
Conv-Resist	Ahra	0.4	0.1	0	0	0	0
Zero Res-Suscept	Cox	0	0	0	0	0	0
Zero Res-Resist	Ahra	14.5	0.8	0	0	0	0
% shoots with secondary mildew in Jun-July							
Untreat-Suscept	Cox	53	78	75	88	80	100
Untreat-Resist	Ahra	68	75	100	100	97.5	100
Conv-Suscept	Cox	5	5	10	10	7.5	25
Conv-Resist	Ahra	0	0	2.5	0	0	0
Zero Res-Suscept	Cox	13	5	15	13	7.5	5
Zero Res-Resist	Ahra	13	5	10	10	5	7.5

The incidence of rots in Cox after long-term controlled atmosphere storage is shown in Table 7. Post harvest rots can be a significant commercial problem in Cox. The rot management system applied in the zero residue programme gave satisfactory control and in most years the lowest incidence of rots was in fruit from the zero residues plots. The predominant rots were brown rot (*Monilinia fructigena*) and *Nectria galigena*.

Table 7. Incidence of rots in the rot susceptible variety Cox after long term CA storage (3.5 °C, 1.25% O_2, < 1% CO_2)

Treatment	2001	2002	2003	2004	2005
Untreated	3.4	14.4	25.2	16.3	18.7
Conventional	0.9	7.2	6.2	7.8	1.4
Zero Residues	3.2	5.5	4.6	3.6	0.7

Pest damage to fruit at harvest is shown in Table 8. A high incidence of pest damage was recorded in the untreated plots in all years and especially in 2004. In 2001 and 2002, pest damage in the zero residues plots was greater than in the conventional plots due to poorer control of rosy apple aphid, sawfly and tortrix. These problems were overcome in 2003 and 2004 by use of two early season thiacloprid sprays, one just before blossom and one at petal fall, by the use of fenoxycarb pre-blossom against tortrix moth caterpillars and by post harvest spraying of pirimicarb against rosy apple aphid. Codling moth incidence was low and it was not necessary to apply sprays of codling moth granulovirus for control.

Table 8. % fruits (averaged across all varieties) damaged by rosy apple aphid (upper part of table) an by all pests (including rosy apple aphid) (lower part of table) at harvest

Treatment	2001	2002	2003	2004	2005
% fruits damaged by rosy apple aphid at harvest					
Untreated	4.7	16.3	2.2	32.3	1.3
Conventional	0.2	0.9	0	0.7	0
Zero Residues	2.8	0.7	0	0	0
% fruits damaged by pests at harvest					
Untreated	18.5	47.0	40.6	67.5	54.1
Conventional	4.3	8.2	6.3	6.6	4.8
Zero Residues	11.2	13.4	6.5	4.9	4.0

4. DISCUSSION

The results achieved in the six years of the project (2001-2006) for the zero pesticide residue strategy were excellent. They indicate that the East Malling Research Zero Residues IPDM programme for apples can give satisfactory results, even on highly disease susceptible varieties in years when there is a high risk of scab. The zero residue programme resulted in as good as or better control of scab than in the conventional. The key to success depends on dealing with disease problems during the winter dormant period and pre-blossom, so that inoculum carryover from one season to the next, and into the post blossom period, is negligible. Assuming disease control pre-blossom has been successful, the main disease problems post bloom were powdery mildew and storage rots.

Control of mildew during the summer in this experiment relied on the use of sulphur, the dose applied and spray interval being determined by mildew risk identified by ADEM. The zero residue strategy gave acceptable mildew control, but it was not as good as the conventional. Studies are ongoing at East Malling Research to investigate alternative methods of mildew control, such as use of biocontrol agents and materials that increase the resistance of apple leaves to mildew. If successful these methods will eventually replace sulphur for mildew control in the summer. Storage rot control was also satisfactory under the zero residue programme, but other approaches are needed for *Nectria* rot and other cheek rots. Pest control in the zero residue system was also satisfactory.

The occurrence of pesticide residues above reporting limits in fresh produce is a significant problem which UK retailers are challenging producers to solve. Help from Agrochemical Companies to set harvest intervals for zero residues is needed. It is possible to greatly reduce the incidence of residues, but total elimination is difficult. Apples are an easier crop to achieve the zero residue objective than some other crops, e.g. soft fruits, where fungicides and insecticides have to be applied very close to harvest. There are many possible ways of reducing the incidence of residues but six years of experimental work has shown that the EMR strategy can be highly successful, even on highly scab susceptible varieties like Gala. However, it is important not to unduly raise expectations, or to make rash claims, which can not be fulfilled in most orchards in most years. Zero residue production requires greater knowledge/expertise and management inputs. Further research and development is needed to find alternative, non-chemical approaches to control of pests and diseases during fruit development.

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