Institution: University of Warwick

Unit of Assessment: UOA5 - Biological Sciences

Title of case study: Adoption of Integrated Pest Management in horticultural crops: benefiting growers, agrochemical companies, agronomy consultants and, ultimately, British consumers

Period when the underpinning research was undertaken: 1 January 2000 - 31 December 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Rosemary Collier	Professor	1987- current
David Chandler	Associate Professor	1990 - current

Period when the claimed impact occurred: 1 August 2013 – 31 December 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

For over two decades, Professor Rosemary Collier and Dr David Chandler have been developing Integrated Pest Management (IPM) tools and approaches to enable UK growers of vegetable and salad crops to optimize pest control in an ecologically and economically sound manner. Their work is enabling the horticultural sector to significantly reduce the volume of conventional pesticides whilst supporting biodiversity and other environmental goals without sacrificing food yield and quality, shaping commercial best practice for fresh produce. They have facilitated the commercialisation and authorisation of biocontrol agents, and supported emergency-use applications for three new-generation pesticide products since 2016. They have developed systems for monitoring and forecasting pest activity, which are provided as a national service online, investigated the use of physical controls in IPM such as fine-mesh netting for high-value vegetable crops, and given advice on effective IPM through articles, talks and demonstrations.

2. Underpinning research (indicative maximum 500 words)

The UK produces around 40% of the fruit and vegetables it consumes (worth GBP1,500,000,000 p.a.) and imports around 60% (GBP2,500,000,000) (Defra, 2019). For growers, effective pest control is more important than ever: invertebrate pests are major constraints to production, as they can result in entire crops being written-off and invariably reduce the quality and yield of fresh produce. With fewer pesticides available, more pesticide-resistant pest populations, and increasing pressures to reduce the environmental impact of crop production, maintaining the high quality standards required by retailers and consumers is ever more challenging.

Since 2000, research by Collier and Chandler has used principles of Integrated Pest Management (IPM) to develop tools and underpinning understanding that help growers to 1) avoid chemical pesticides whenever possible and 2) when essential, deploy pesticides more effectively. IPM involves the coordinated, precision use of multiple tactics for optimising pest control in an ecologically and economically sound manner – integrating conventional pesticides with biopesticides, using pest and disease forecasts to make treatment decisions, and cultural methods including rotations, clean plant material, resistant varieties, pheromone technology, biocontrols, and physical controls. These ecologically-sound processes are technically very challenging to implement without new supporting frameworks. Collier and Chandler's research provides new scientific tools as well as examples which promote improved practice.

Development of new plant protection products for horticulture

Since 2010 Collier and Chandler have established the optimum application methods, efficacy and crop safety of novel crop protection products in collaboration with the Agriculture and Horticulture Development Board (AHDB), growers, agrochemical companies (DuPont, FMC,

Syngenta), and collaborators Agri-Food Solutions, RSK ADAS, NIAB EMR, and Stockbridge Technology Centre. Collier led the research on field vegetable pests in the Horticulture LINK project, Sustainable Crop and Environment Protection – Targeted Research for Edibles (SCEPTRE) (2010–2014) [G1], and is the science lead for the follow-up SCEPTREPlus (2017-22, [G2]). Warwick research provided the efficacy testing of new generation products *Teppeki* (flonicamid) against willow-carrot aphid (*Cavariella aegopodii)* on carrot and parsnip in 2015; Benevia 10OD (cyantraniliprole) against diamondback moth (*Plutella xylostella*) on brassicaceous vegetable crops in 2016; and FLiPPER (fatty acids C7-C20) for aphid control on field vegetable crops in 2018 and 2019.

Improving the performance of biopesticides

In 2011 Chandler, with Tatchell and Grant, funded by the RCUK Rural Economy and Land Use programme, demonstrated that the UK/EU plant protection products regulatory system was unintentionally impeding the commercialisation of environmentally friendly biopesticides by treating them as synthetic chemicals [3.1]. Their work led to a revised system that kickstarted a new wave of biopesticide development. Since 2014, Chandler has continued to investigate entomopathogenic fungi as biopesticides for horticultural crops, including aphid control on field vegetables [3.2]. From 2015, he has investigated suboptimal performance of biopesticides in commercial practice (AHDB-funded Application and Management of Biopesticides for Efficacy and Reliability project, [G3]). The project has led to improved application practices and is pioneering the development of biopesticide decision support systems to aid precision application.

Developing pest forecasting and monitoring tools

Throughout the REF period, Collier's research has underpinned the development of new pest forecasting tools. From 2004 to 2007, Defra funding improved model software and supported model uptake by growers. Collier demonstrated that interpolated geographically continuous temperature data and topographical data could greatly improve local phenology estimates for three key pests: blackcurrant gall mite (*Cecidophyopsis ribis*), diamondback moth, and large narcissus fly (*Merodon equestris*) [3.3]. A new forecasting model in 2013 forecast black bean aphid flights. Diamondback moth and silver Y moth are highly damaging to brassica and lettuce crops respectively, but infestations are hard to forecast because they result from summer migrations from continental Europe. From 2015, Collier has been developing novel systems using networks of pheromone traps, in-trap cameras, and European citizen science data, which will allow reliable warnings for these pests for the first time [e.g. 3.4].

Development of integrated strategies to control pests

Research by Collier and Chandler has pioneered IPM strategies for a range of horticultural crops [3.2-3.7]. Strategies are based on a fundamental understanding of pest life cycles, chemical and biocontrol agents, cultural practices and host plant resistance. With G's, a major UK and European supplier, and Marks & Spencer (2011-2013) the team investigated strategies to control cabbage root fly on radish crops without use of insecticides. They demonstrated that existing practices of sowing crops sequentially on the same land allowed larvae from eggs laid on waste from preceding crops to move onto the new crop, causing new infestations under net covers when this approach was deployed [3.6]. Between 2014 and 2016, Collier collaborated with G's to demonstrate that fine mesh netting controlled pest bugs on celery crops and eliminated the need for an insecticide. Collier also coordinated the ERA-net (European Research Area Network) project FlyIPM, with scientists from eight countries, which reviewed IPM for root-feeding fly pests of vegetables across Western Europe and evaluated new strategies [3.7]. It is clear that this pioneering work will become increasingly important in the future, as farming systems are redesigned to enable conservation of biodiversity and a reduction in staples in favour of more nutritious vegetable crops, while at the same time maintaining quality standards, reducing waste, and significantly reducing the volume of chemical pesticide inputs**.**

3. References to the research (indicative maximum of six references)

[3.1] **Chandler, D.**, Bailey, A, **Tatchell, G.M., Davidson, G., Greaves, J.** and **Grant, W.** (2011). *The development, regulation and use of biopesticides for integrated pest*

management. Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 366(1573), 1987–1998. doi:10.1098/rstb.2010.0390
[3.2] **Prince, G.** and **Chandler, D.** (2020). *Susceptibility of Myzus persicae, Brevicoryne brassicae and Nasonovia ribisnigri to fungal biopesticides in laboratory and field experiments.* Insects, 11(1). 55. doi:10.3390/insects11010055
[3.3] Jarvis, C.H. and **Collier, R.** (2002). *Evaluating an interpolation approach for modelling spatial variability in pest development*. Bulletin of Entomological Research, 92(3), 219-231. doi:10.1079/BER2002160
[3.4] Wainwright, C., **Jenkins, S., Wilson, D., Elliott, M., Jukes, A.** and **Collier, R.** (2020). *Phenology of the Diamondback Moth (Plutella xylostella) in the UK and Provision of Decision Support for Brassica Growers*. Insects, 11(2), 118. doi:10.3390/insects11020118
[3.5] George, D. R., **Collier, R.** and Port, G. (2009). *Testing and improving the effectiveness of trap crops for management of the diamondback moth Plutella xylostella (L.): a laboratory-based study*. Pest Management Science 65 (11), 1219 - 1227 doi: 10.1002/ps.1813
[3.6] Witkowska, E., Moorhouse, E.R., **Jukes, A., Elliott, M.S. & Collier, R.** (2018). *Implementing Integrated Pest Management in commercial crops of radish (Raphanus sativus).* Crop Protection 114, 148-154. doi:10.1016/j.cropro.2018.08.008
[3.7] **Collier, R**., Mazzi, D., Folkedal Schjøll, A., Schorpp, Q., Thöming, G., Johansen, T.J., Meadow, R., Meyling, N.V., Cortesero, A.-M., Vogler, U., Gaffney, M.T., Hommes, M. (2020). *The potential for decision support tools to improve the management of root-feeding fly pests of vegetables in Western Europe*. Insects 11, 69; https://doi.org/10.3390/insects11060369

Grants:
[G1] PI **Collier, R**., Sustainable Crop and Environment Protection – Targeted Research for Edibles: SCEPTRE, Horticulture LINK project , Defra, 01/10/2010 – 30/09/2014, GBP160,000
[G2] PI **Collier, R**., Sceptre plus, AHDB, 03/04/2017 – 02/04/2021, GBP1,218,880
[G3] PI **Chandler, D**., Application and management of biopesticides for efficacy and reliability (AMBER), AHDB, 01/01/2016 – 31/12/2020, GBP545,995

4. Details of the impact (indicative maximum 750 words)

Warwick IPM research supports sustainable high-quality vegetable production across the horticultural sector in the UK and Professor Collier and Dr Chandler work closely with the Agriculture and Horticulture Development Board (AHDB), which is funded by the agriculture and horticulture industries. Warwick's "world-leading" expertise and facilities are key "*to generat[ing] new knowledge on agronomic, biological, chemical and genetic control agents for diseases, pests and weeds, together with pest and disease forecasts and decision support tools. The technical knowledge and innovations have enabled growers to improve their pest and crop management systems"*, according to the AHDB's Research Director [5.1].

Access to new chemical and biopesticide plant protection products

Due to the prohibitive costs of bringing a new plant production compound to market – approximately GBP270,000,000 for a synthetic chemical pesticide – it is challenging for companies to justify these additional costs for what are effectively minor crops, yet new active ingredients are essential when older products are withdrawn. Collier and Chandler cooperated with multiple agrochemical and biopesticide companies to facilitate the delivery of new crop protection products for horticulture. Syngenta are one of many companies accessing Warwick's expertise: "*Warwick's innovative crop protection research is also important to us because they have great expertise in the minor crop sector. They have helped us to develop our product offer for the vegetable industry, extending our current product offer into new crop areas and introducing new products to the market with development trials*" [5.2]. Collier's work with DuPont (now FMC) informed the formulation and application method for Cyazypyr®, which gives selective control of cabbage root fly and diamondback moth while not exposing beneficial arthropods such as hoverflies and spiders. "*Without Warwick's trials work, I believe that some key uses of insecticides would not have been developed and, without the knowledge transfer, products would not have been used as effectively"* [5.3].

Collier is one of the lead scientists on AHDB's SCEPTRE and SCEPTREPlus [G2] programmes, which drive sustainable plant protection in horticulture. She provided key evidence to support the AHDB's Horticulture Extension of Authorisation for Minor Use (EAMU) programme, which obtains approvals for new crop protection products on horticultural crops. Warwick's efficacy data on three products supported emergency-use applications between 2016 and 2020:

a) Teppeki®: Warwick's aphid forecast was used to support AHDB's emergency 120-day authorisation applications to the Chemicals Regulation Division (CRD) for Teppeki®, a selective aphicide, in 2018, 2019 and 2020. "*This has been important to the carrot-growing sector, with a value of around £120M [GBP120,000,000] because of limited aphid control options … Teppeki's different mode of action improves pesticide resistance management options"* [5.1].

b) Benevia 10OD®: Diamondback moth can lead to significant vegetable brassica crop damage, with losses of up to 40% for Brussels sprout crops, 15% for swedes, and 10% for cabbages. Control can be difficult due to resistance to pyrethroid insecticides (which are also toxic to beneficial insects). In 2016 damage was estimated at around GBP9,000,000 in the UK. Warwick's pest pressure data supported AHDB's successful 120-day emergency authorisation applications for Benevia 10OD® in 2016, 2019 and 2020 [5.1].

c) FLiPPER®: This biological insecticide provides growers with a "critical new product" [5.1] following withdrawal of pymetrozine and pyrethrins in 2020; it provides fast-acting control of whitefly, aphid and two-spotted spider mite on a range of field and leafy vegetable and fruit crops including strawberry, tomato and cucumber.

Advice on improved biopesticide performance

Warwick's research is the leading resource in the UK for biopesticide best practice. Following Warwick's inputs to help revise the 2007 UK Pesticides Safety Directorate Biopesticides Regulation Scheme and the 2009 EU Sustainable Use of Pesticides Directive, approved biopesticide products have increased tenfold in the EU, from 10 in 2008 to 105 in 2017. Working closely with AHDB and growers, Warwick has developed and shared biopesticide best practice, raising awareness of how these products work to improve control using biopesticides. Chandler has led a regular series of talks, around 10 each year since 2016, attracting over 300 delegates from the horticultural industry; he has also held demonstrations and written outreach articles for growers, providing information on sprayer husbandry, equipment calibration and best field practice. Feedback indicates a favourable cultural shift and improved control [5.1].

Fargro, the lead authority on biopesticides and IPM-compatible products for the horticultural sector, consider Warwick *"[our] first port of call for assistance with innovative work on biopesticides and crop protection solutions*" and states that *"Fargro has relied on Warwick's excellent services, staff and research capabilities"* [5.4]. Warwick's biopesticide benchmarking has informed Fargro's technical support and support literature for its 4,000 customers. Warwick's research on the microbial biofungicide AQ10®, an obligate parasite of powdery mildew fungi, led Fargro and 30MHz to develop a decision support system for growers embedded within their crop monitoring platform. This forecasts the likely occurrence of powdery mildew on crops such as aubergine, courgette, cucumber, tomato and strawberry, and recommends a window for early, effective application of AQ10 [5.4].

Independent pest monitoring and forecasting services

Since August 2013, Collier has provided over 386 forecasts of many field vegetable pests in the weekly AHDB Pest Bulletin service, a collaboration between Warwick, AHDB and Syngenta. Considered a key service for the horticulture sector, the bulletin helps its readership of around 3,000 growers to treat crops "*in a reactive manner instead of prophylactically*" [5.2]. In addition, Collier and Agrii, the UK's leading provider of agronomy services, combine Warwick's carrot fly forecasting model with UK-wide weather data to provide live, accurate and timely advice via mobile devices. This *"is likely to have improved the economic performance of carrot crops"* as well as *"improved our relationships with our customers"* [5.5]. Agrii has also used the black bean aphid migration forecast since 2014 to warn of high-risk periods and the forecasts have "*reduced*

the economic and reputational risks to growers" [5.5]. AHDB's survey (2018-19) on the use of their monitoring and forecasting services found that 88% of users rated the pest bulletin service as 'quite or very useful', with the service enabling the targeting of in-field monitoring, targeting of sprays and determining spray frequency [3.7].

Adoption and reach of IPM strategies to control pests

There are no insecticide seed treatments approved for use on radish against cabbage root fly larvae, which feed on radish bulbs. The 2016 and 2019 AHDB guidance for pest insects infesting Brassica crops, written by Collier, recommended IPM strategies including monitoring and net covers [5.6]. G's, the UK's largest producer of radish for multiple retailers (market value of around GBP11,000,000) has adopted the use of net covers for commercial radish production based on Warwick's research on crop protection, changing land management practices to break the pest's life cycle. This has doubled their yield on a third less land, reduced waste, lowered staff costs associated with sorting rejected produce, and improved G's relationships with its retailer customers. They state that *"Warwick has been our 'go to' place for specialist knowledge and expertise"* and that the Warwick research *"was key to us adopting this control method in 2014 and developing and investing in the new growing system over the next 3 years* [5.7, 3.6]. The Red Tractor Assurance Scheme's 'Radish Crop Module' (2016) also recommends fine mesh netting for control without the use of insecticide [5.8].

Many AHDB best practice guidance factsheets recommend IPM strategies. Examples include cultural approaches for the management of capsid bugs on celery crops, particularly devastating in organic celery crops with potential annual losses of GBP2,000,000: "*…crop covers made of fine mesh netting to exclude all stages of Orthops spp. This approach successfully excludes the bugs, although it may have other consequences for crop management*" [5.9]. Also Collier's evaluation of novel insecticide and bioinsecticide sprays to control asparagus beetle adults and larvae have "*identified more sustainable control methods such as improved monitoring of the pest and improved crop residue management at the end of the season, which have been recommended as best practice"* [5.1, 5.10].

Warwick's research and outreach on IPM in vegetable crops has given the UK's commercial horticulture sector more sustainable, environmentally-friendly and economically viable crop protection practices. Warwick's innovations and dissemination of best practice have helped increase production, reduce waste and helped international agronomy companies avoid revenue losses of millions of GBP.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] AHDB written statement verifying impact on IPM strategies and adoption of tools, access to crop protection products and industry best practice
[5.2] Syngenta written statement verifying impact of pest bulletin and product development
[5.3] FMC written statement verifying impact on product development
[5.4] Fargro written statement verifying impact on technical support
[5.5] Agrii written statement
[5.6] AHDB Factsheet 11/19 Pest insects infesting Brassica crops https://tinyurl.com/h90sa96z
[5.7] G's written statement.
[5.8] Red Tractor Assurance Scheme's Radish Crop Module (2016) recommends use of fine mesh netting to control cabbage root fly https://tinyurl.com/1hkthxma
[5.9] AHDB Factsheet 11/18 'Management of capsid (mirid) bugs infesting outdoor celery crops recommends use of fine mesh netting https://tinyurl.com/5p72oe3o
[5.10] AHDB guidance on the sustainable control methods for asparagus beetle recommends improved monitoring and cultural controls https://tinyurl.com/5g6oc9kf