Institution: Lancaster University

Unit of Assessment: UoA7 – Earth Systems and Environmental Sciences

Title of case study: Increased yields in global food production from improved pest control based on ecological research.

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

Our research has led to increased crop yields and a reduction in the need for synthetic pesticides, through a new patented technology of treating seed with the natural plant signalling molecule, jasmonic acid. Lancaster's fundamental research in to the biology of plant-herbivore interactions showed for the first time that jasmonic acid (JA) seed treatment of a range of crops improved pest resistance for many weeks after germination, without the physiological costs of foliar JA application. We have patented this JA seed treatment technology (patents awarded in USA, Canada, Japan, Europe, Australia, New Zealand, and Mexico, applied for in three other major countries) and licensed it to BASF (previously Becker Underwood). JA seed treatments have been available to growers in the USA since 2010, and the technology is being rolled-out internationally for a range of major global crops.

2. Underpinning research (indicative maximum 500 words)

Lancaster's pioneering research in to the ecology and ecophysiology of three way interactions between plants, insect herbivores and fungal pathogens[1-3] funded by NERC (NERC GR3/9109 and GR3/11952) with Paul and others as PIs between 1994 and 2002 totalling £325,300*)* led to new insights in to the mechanistic links between the benefits (reduced damage) and costs (reduced growth) of induced resistances controlled by jasmonate (JA) signalling. Jason Moore, then a NERC-funded PhD student (2000-2003, supervised by Paul and Taylor), showed that increased resistance to beetle attack in *Rumex* spp. was directly linked to reduced leaf expansion through changes in the biophysical properties of leaves that led to leaf stiffening. We also showed that these effects could be stimulated by the exogenous application of jasmonates[4-5]. Seeing many published reports of attempts to use foliar jasmonate sprays in crop pest control, Moore recognised that their commercial failure could be linked to the negative effects on yield that resulted from the associated plant physiological costs that he was investigating. The scientific insights obtained during this PhD led us to hypothesise that applying jasmonates to seed might induce resistance without the associated detrimental effects. Moore also recognised that this approach was sufficiently distinct to allow IP protection that would not be possible with spray applications. He undertook initial experiments with spider mites on tomato and proved that JA seed treatments did deliver jasmonate-mediated resistance without the associated biological costs[6]. Those data, and Moore's commercial insight, led Paul, Taylor and Roberts to win a NERC follow-on award to investigate the commercial potential of the jasmonate seed treatment, leading to patent applications and commercial uptake (see section 4). With funding from Defra (PS2121: £342,101) we investigated a wider range of crops, pests, and pathogens, and began to clarify that jasmonate seed treatment did not itself induce resistance but "primed" crops for a greater and more rapid response when attacked, explaining the lack of growth reduction from the treatment[6]. Further mechanistic research has continued with BBSRC funding (BB/G021791/1, £683,085) which focussed on the epigenetic changes underlying priming by the jasmonate seed treatment.

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

** indicates the three references that were most central to the impact that has been achieved.*

1. Hatcher, P.E., Paul, N.D. *et al*. (1994) The effect of a foliar disease (rust) on the development of *Gastrophysa viridula* (Coleoptera, Chrysomelidae). *Ecological Entomology*, **19,** 349-360.
2. Hatcher, P.E., Paul N.D. *et al*. (1994) The effect of an insect herbivore and a rust fungus individually, and combined in sequence, on the growth of 2 Rumex species. *New Phytologist*, **128,** 71-78.
3. Hatcher, P.E. and N.D. Paul (2000) Beetle grazing reduces natural infection of *Rumex*

obtusifolius by fungal pathogens. *New Phytologist*, **146,** 325-333.
4*. Moore, J.P., et al. (2003 Reduced leaf expansion as a cost of systemic induced resistance to herbivory. *Functional Ecology*, 2003. **17,** 75-81.
5*. Moore, J.P., et al. (2003) Exogenous jasmonic acid mimics herbivore-induced systemic increase in cell wall bound peroxidase activity and reduction in leaf expansion. *Functional Ecology*, **17,** 549-554.
6*. Worrall, D., et al. (2012) Treating seeds with activators of plant defence generates long lasting priming of resistance to pests and pathogens. *New Phytologist*, **193,** 770-778.

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

From a PhD student hypothesis in 2003, the jasmonate seed treatment has been rapidly commercialised for use in global production, entering the market in the USA in 2010. Use of the seed treatment is benefitting growers by improving crop performance and will ultimately reduce the need for pesticide inputs into agriculture. Commercialisation was achieved as follows.

In 2004, after completing his NERC-funded PhD in the Lancaster Environment Centre (LEC), Moore was awarded a fellowship from the Horticultural Development Corporation designed to support knowledge transfer from basic research to its application[A]. The fellowship included the initial development of the seed treatment that was then expanded through the award to LEC of the NERC follow-on award[B] which also supported the initial steps of intellectual property assessment and protection, based both in the effectiveness of the technology and the low toxicity of jasmonic acid and its analogues.

In 2007, we submitted a patent to protect the technology (International Patent Publication No. WO 2008/007100).[C] We also assigned the technology to Plant Bioscience Limited (PBL), a company originally founded jointly by the John Innes Centre and the Sainsbury Laboratory, with BBSRC subsequently becoming a third partner, so that PBL now supports technology development for a wide range of customers (http://www.pbltechnology.com/). We then worked with PBL to promote the seed treatment technology to potential end-users. There was considerable commercial interest in this technology. This was based partly on the mechanistic understanding that the technology simply primed the crop to deploy its natural defence more effectively when challenged by a pest, which was seen as reducing the risk of pests developing resistance. The interest also resulted because the JA seed treatment was seen to provide a valuable new approach in a market where the range of available control measures was becoming increasingly limited in many countries due to regulatory restrictions on many conventional pesticides. In 2008, a world-wide exclusive licence for the use of the seed treatment was assigned to Becker Underwood, an international agrochemical company (www.beckerunderwood.com/news/becker-underwood-granted-exclusive-marketing-rights-for-patented-new-seed-treatment-technology/), subsequently (2012) acquired by BASF (http://www.basf.com/group/pressrelease/P-12-419). Since 2008, the companies have undertaken their own commercial field-trials on a range of crop systems in North and South America and, from 2010, have invested in trials required for formal registration of the technology as a pesticide treatment under EU regulations. Work towards registration is also progressing in Australia, Mexico, Brazil and Argentina[D]. Apart from extending the geographical spread, the JA seed treatment technology is also in development for use on maize, wheat, rice, pulses, cotton and vegetables.[D] The results from these trials are sufficiently positive for PBL to proceed with patents and for BASF to enter pesticide registration procedures in a range of countries. Patents have been granted in the USA (8,115,053 (2010) and 8,507,756 (2013) which extends the scope of the claims), Canada (2,657,057), Europe (2,066,176), Australia (2,007,274,083), New Zealand (574,108), Japan (532,293) and Mexico (304,248). Following the European grant the companies have selected Austria, Belgium, Bulgaria, Switzerland, Germany, Denmark, Spain, France, UK, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania and Turkey for the initial national patents. Applications are being examined in South Korea, Argentina and Brazil.

Having acquired the licence, Becker Underwood proceeded very quickly to roll-out the technology into commercial use. The Business Development Manager responsible for the technology at PBL has noted "*This product development timeline represents a major achievement and reflects the strength of the innovation, the clear market opportunity ..... Within the agricultural field PBL has never experienced such a short development period from initial testing (and indeed filing of the patent application) to product launch which was only two years*."[D] The commercial use of the JA seed treatment started by incorporating JA as an integral part of their BioStacked® seed technology, the subject of an additional patent by Becker Underwood (US2012/0077674 A1). Between 2012 and the present, Becker Underwood's BioStacked® technologies, notably their HP Vault™ product, a flagship product for the company, which has been used primarily for soybean and peanut in the USA, with more recent application for maize. In February 2013, the US EPA formally approved the JA seed treatment as a bio-insecticide in February 2013 under the trade name Tariss™, initially for pest control on canola, rapeseed, mustard, safflowers and sunflowers.[E] The EPA also recognised the high level of environmental and health safety of the technology by granting exemption from the requirement of a tolerance for residues[F], accepting the claims we had made when developing the patent. Pesticide registration in Canada is pending approval and the application for registration in Europe is planned for 2014. The company has detailed plans for the technology to be rolled-out internationally as the patent and pesticide registration processes are completed.

When Becker Underwood were acquired by BASF in late 2012, the BASF statement recognized the key role of Becker Underwood's innovative seed treatments "…*We are impressed with Becker Underwood's ability to translate growers' needs into innovative, tailor-made solutions that can promote higher yields while conserving resources….particularly in the rapidly-growing seed treatment market, we will be able to develop innovative solutions for agriculture…*"[G]

It remains hard to translate this measurable impact in the agrochemical industry in to the wider economic benefits to growers, but some initial estimates can be made from the use of the technology to date in the US soybean market. Current sales represent treatments for seed sufficient to sow approximately 2,500,000 hectares, i.e. within two years of its introduction the technology is now used over roughly 8% of the total area of soybean in the USA. Based on the company's field trial data, yield increases of 2-7% are attainable from JA-containing treatment for soybean seed[D]. Taking the most conservative yield increase (2%) and the most recent (2011) data from the UN Food and Agriculture Organisation (FAO) for average yields and farm-gate price for US soybean (http://faostat.fao.org/) such increases would represent an increase of 0.06T/ha with a value of approx. $25/ha. Based on the use of seed treatment over 8% of the planted area, this yield increase is equivalent to an increase of 135,000T in US soybean production, with a farm gate value of approx. $60M in this one crop for one year alone, even with a conservative estimate of the yield benefits (2% not 7%). If these same assumptions are applied to the global soybean crop, and also assuming no further increase in penetration beyond the 8% currently seen in the USA, the use of the JA seed treatment globally would result is an increase in annual global production of 0.4 million tonnes, worth $175 million.

Clearly, another impact that is expected to arise from the use of the jasmonate seed treatment is a reduction in the need for chemical pesticides used in commercial crop production. We have always been clear that the seed treatment will be an additional tool in the armoury of pest control that will continue to include chemical pesticides. However, the effectiveness of the seed treatment in pest control, now confirmed by independent research[H] to include nematodes, provides a solid basis for reduced pesticide use in many crops. So far as we are aware, at this early stage in the commercial use of the technology, there is no quantification of any such reduction even in soybean, However, in terms of pesticide usage in that crop, the US Department of Agriculture (USDA) identifies six major and ten minor pests attacking the US soybean crop. USDA data also shows that chemical pest control in US soybean involves a suite of approximately twenty active ingredients of which six (two organophosphates (OPs) and four synthetic pyrethrenoids) dominate. Even given the current use of on just this crop, modest reductions in pesticide usage per unit area as a result of the jasmonate seed treatment would result in substantial total reductions in input in to the environment. These socioeconomic and environmental impacts of the jasmonate seed treatment are expected to grow as the technology will continue to be strongly developed by BASF for the foreseeable future. As PBL's Business Development Manager has said "*Over the next few years it is therefore expected that the .... impact of the JA seed treatment will be increased substantially*".[D]

The impact resulting from rapid take-up of our seed treatment technology has been recognized by external bodies. Prof Alan Thorpe, then Chief Executive of NERC, also said "*We're pleased our follow-on funding has allowed this research to be developed into a commercially useful technology. This is a casebook example of how we envisaged the scheme would work at the outset*."[I] The technology was featured in NERC's Planet Earth[J] as an exemplar for successful follow-on funding and was also highlighted in the NERC annual report for 2008-9[K]. It was also recognised in the 2012 white paper on Innovation and Research Strategy for Growth[L] as a highlight of the impact of RCUK-funded research.

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

A. Moore & Paul. Developing novel approaches to the sustainable production of ornamentals in the UK (Fellowship to Moore). UK Horticultural Development Council. Apr 04-Mar 07. £175,803 (http://www.hdc.org.uk/project/developing-novel-approaches-sustainable-production-ornamentals-uk-hdc-research-fellowship-4)
B. Paul, Taylor, Roberts. Evaluating the potential of a novel method of inducing pest resistance using a natural plant product. NERC. Jan 06-Dec 06. £59,000 (NERC NE/D521581/1)
C. International Patent Publication No. WO 2008/007100 Roberts, Paul, Taylor, Croft, Moore. Improvements in and relating to crop protection, 2007. http://www.wipo.int/patentscope/search/en/WO2008007100
D. Letter from Business Development Manager Plant Biosciences Ltd.
E. Methyl Jasmonate BRAD (Biopesticides Registration Action Document) Methyl Jasmonate PC Code : 028100 (http://federal.eregulations.us/rulemaking/document/EPA-HQ-OPP-2012-0134-0006).
F. Exemption from the Requirement of a Tolerance: Methyl Jasmonate (https://www.federalregister.gov/articles/2013/04/17/2013-08829/methyl-jasmonate-exemption-from-the-requirement-of-a-tolerance)
G. BASF Press release: 20th September 2012 (http://www.basf.com/group/pressrelease/P-12-419).
H. Pankaj, M *et al* (2013) Differential defence response due to jasmonate seed treatment in cowpea and tomato against root-knot and potato cyst nematodes. *Nematology*, **15**, 15-21. DOI: 10.1163/156854112X641754.
I. Joint press release from NERC, PBL, Becker Underwood and Lancaster University: June 2009
J. Ledder P. Seeds of Change. NERC Planet Earth, Autumn 2008, pp 18-19. (http://www.nerc.ac.uk/publications/planetearth/2008/autumn/aut08-seeds.pdf)
K. Natural Environment Research Council Annual Report and Accounts 2008-09: Knowledge Exchange. http://www.nerc.ac.uk/publications/annualreport/2009/knowledgeexchange.pdf
L. BIS ECONOMICS PAPER NO. 15. Innovation and Research Strategy for Growth page 86 https://www.gov.uk/government/publications/innovation-and-research-strategy-for-growth.