Institution: University of Bath

Unit of Assessment: A5 Biological Sciences

Title of case study: Novel and sustainable control of two major fungal diseases of a world commodity crop

1. Summary of the impact

Strategies have been developed to combat two fungal diseases that can devastate production of palm oil, a world commodity supplying 40% of world vegetable oil and valued at $46 Bn (USD):
(i) A novel fungicide treatment was designed to eradicate from seeds *Fusarium*, a lethal fungal pathogen in Africa (responsible for yield losses of up to 54% prior to death of infected palms), and prevent inter-continental disease spread.
(ii) Improved disease resistance screening for *Ganoderma,* the second major pathogen, found in South East Asia and responsible for estimated losses of £2Bn per annum in Malaysia alone, continues to identify disease-resistant lines for cultivation. Through collaborative projects, these strategies have been adopted as industry standards in Ghana, Congo, Malaysia and Indonesia. These sustainable approaches to disease control provide increased turnover and sales, and enhance food security at both local and international levels.

2. Underpinning research

In Africa, the centre of origin of oil palm, a soil-borne fungal pathogen *Fusarium*, has caused enormous yield losses (see Section 4) resulting in reduced calorific intake to villagers, and reduced profits to oil palm-producing companies and smallholders. Consequently, the productive oil palm regions have moved to Malaysia (2012 palm oil value approximately £14 Bn) and Indonesia, that combined produce 86% of world palm oil. The Bath team led by Dr Richard Cooper initially revealed (1994) that *Fusarium* can be found inside as well as on oil palm seeds in Africa [1]. Genetic analysis of *Fusarium* isolates in 1993 revealed outbreaks in South America originated from seed exported from Ivory Coast [2]. This finding resulted in implementation of seed quarantine to detect *Fusarium*. The pressing need to eradicate the pathogen from seeds led to identification of a suitable fungicide, but seed immersion proved ineffective against *Fusarium inside* seeds. The Cooper laboratory showed in 1994 that vacuum infiltration allowed fungicide penetration through seed germ-pores and eliminated *Fusarium* [1]. The application of this approach by industry and for seed quarantine is detailed in Section 4.

In South East Asia, crop monoculture has resulted in emergence of another devastating fungal disease, basal stem rot caused by *Ganoderma* [3-5]. The only effective solutions are to (a) detect and utilize disease resistance and (b) prevent disease spread [5]. Disease resistant palm lines are required to prevent loss of yield or death of trees. Identifying resistance requires defined conditions and detailed knowledge of infection. The Bath group radically improved screening in Indonesia by (a) standardizing the methodologies for resistance screening and (b) shading inoculated seedlings. We showed that shading mimics that provided by the palm canopy and prevents soil overheating in the tropical sun. Temperatures of exposed soil can exceed 40^{o}C which inhibits or kills the pathogen (resulting in false negative screening results) [3]. The widespread uptake of this adaptation is described in Section 4.

Key members of the Cooper laboratory:
Post-doctoral Dr J. Flood (1983-1994); research assistant, Dr R. Mepsted (1988-1994); post-graduates, A. Buchanan (1997-2000), R.W. Rees (2002-2005), M. H. Rusli (2008-2012), M. A. Wahab (2011-2014). No other UK institution is working in this area.

3. References to the research

[1] Flood, J., Mepsted, R.,Cooper, R.M. (1994) Population dynamics of *Fusarium* species on oil palm seeds following chemical and heat treatments. *Plant Pathology* ***43,*** 177-182. DOI: 10.1111/j.1365-3059.1994.tb00568.x
[2] Flood, J., Whitehead, D.S., Cooper, R.M. (1992) Vegetative compatibility and DNA

polymorphisms in *Fusarium oxysporum* f.sp. *elaeidis* and their relationship to isolate virulence and origin. *Physiological and Molecular Plant Pathology*. ***41***, 201-215. DOI: 10.1016/0885-5765(92)90011-J
[3] Rees, R. W., Flood, J., Hasan, Y., Cooper, R. M. (2007). Effect of inoculum potential, shading and soil temperature on root infection of oil palm seedlings by the basal stem rot pathogen *Ganoderma boninense*. *Plant Pathology* **56**, 862-870. DOI: 10.1111/j.1365-3059.2007.01621.x
[4] Rees, R. W., Flood, J., Hasan, Y., Potter, U., Cooper, R. M. (2009). Basal stem rot of oil palm (*Elaeis guineensis*); mode of root infection and lower stem invasion by *Ganoderma boninense. Plant Pathology* **58**, 982-989. DOI: 10.1111/j.1365-3059.2009.02100.x
[5] Rees, R. W., Flood, J., Cooper, R. M. 2012. *Ganoderma boninense* basidiospores in oil palm plantations: evaluation of their possible role in stem rots of oil palm (*Elaeis guineensis*). *Plant Pathology* **61**, 567-578. DOI: 10.1111/j.1365-3059.2011.02533.x

Details of grants and studentships that have supported this work:
£ 84,000 Malaysian Ministry Education 2011-2014; Epidemiology & control of *Ganoderma.*
£ 113,500 Malaysian Palm Oil Board 2008-2012 and 2013; *Fusarium* detection and resistance.
£ 2,000 FELDA/FASSB 2011; Training for 3 months for research staff on *Ganoderma*.
£ 98,000 Agrinos; Research included novel soil treatment for *Fusarium* of oil palm.
£ 50,000 BBSRC (Industrial CASE: LONSUM &CABI) 2002-2005; Resistance to *Ganoderma*.
£ 40,000 BBSRC (Industrial CASE with PBI Cambridge) 1997-2000; Palm resistance genes.
£ 84,900 EU. 1994-1997; Optimization of oil palm breeding techniques to control *Fusarium.*
£ 265,400 Unilever Plantations & Plant Science Group, total from several grants between 1991-1994; Resistance to Fusarium.
£37,373 EU 1990-1993; Oil palm defence mechanisms to *Fusarium oxysporum*.

4. Details of the impact

Background

Commercial oil palm is a world commodity providing around 40% of world vegetable oil, valued at $46 billion (USD), but is constrained by the two fungal diseases caused by *Fusarium* and *Ganoderma*. Palm oil is important globally for human nutrition and as an income generator at local and national levels (80% for food purposes, remainder includes biodiesel and detergents). The prevention of these diseases and development of resistance to them also has significant quality of life benefits for the sustainable existence of smallholders and alleviating rural poverty. Approximately 40% of the total area under oil palms in Malaysia is run by an estimated 500,000 smallholders on very low incomes (FELDA [A]). In Indonesia where >17% are below the poverty line, 41% of plantations are owned by smallholders. The industry there employs approximately 2 million people [B].

Past yield losses from *Ganoderma* have been estimated at 19-46% in Malaysia and in 85% death of mature palms in Indonesia [C]. One estimate gives annual losses in Malaysia as £2 Bn (Malaysian Palm Oil Board; MPOB [A]). Fusarium wilt in Africa reduces yield by 30-54% before the typical death of the palm [D]. The gain from disease prevention and control is clearly considerable. The control methods described are sustainable and bring environment benefits.

Impact from *Fusarium* research

1. Improving the performance of existing businesses: efficiency, throughput, seed sales and prices. Seed treatment as developed at Bath and patented [E] is currently adopted by two main companies:
(i) *Feronia* in Democratic Republic of Congo (DRC), since 1911 one of the largest palm oil producers in Africa with 107,892 hectares and around 400 employees. The *Feronia* website refers to, *"In a joint research project with Bath University, Yaligimba Research Station [*DRC*] developed a technique which removes all fungi including Fusarium spores, even those between the kernel and shell. The seed is subjected to this special treatment prior to export."* [F].
(ii) Ghana-Sumatra (CSIR-OPRI) in Ghana, who have an extensive collection of oil palms gathered from wild populations in the region. Ghana Sumatra is a seed company recently set up as the

research link with LONSUM, Indonesia [A]. *Ghana-Sumatra* commented:
"*A market lead for seed sales is given by certifying our seed is Fusarium-free; at our request he [R Cooper] adapted and shipped equipment in 2011; it is currently treating 2 million seeds p.a; treatment has allowed a price increase of 15%".* [F].

Also the method is used by CABI-Europe-UK who provide seed quarantine for shipments exported from Africa, because the pathogen is not found in South East Asia or most of South America [A]. This creates an effective intercontinental barrier to disease spread. *CABI-Europe-UK* has been charging for seed quarantine service between other countries and S E Asia for more than a decade. They state *"The current methodology used at CABI E-UK is an adaptation of...this technique initially developed in 1994 by research staff in Dr Cooper's laboratory*" [F].

2. Delivery of highly skilled people:
a) A main team member into a global role: Dr Julie Flood was a member of the Cooper laboratory for about 11 years working on *Fusarium*, then secured a position with Centre for Agricultural Biosciences International (CABI) and is now Global Director-Commodities [A].
b) A Malaysian researcher into a key country position: M. Rusli trained at Bath in *Fusarium* research; employed in 2012 by MPOB in oil palm biosecurity, in particular to prevent *Fusarium*.

3. Technology Transfer:
In 2011 apparatus was designed in the Bath laboratory to handle thousands of seeds per treatment and sent to Ghana (Oil Palm Research Institute). A visit there by Cooper in 2010 demonstrated superior methods for sampling and screening palms for *Fusarium* infection [G].

Impact from *Ganoderma* research
As a direct result of our work [3], shading is used routinely in Sumatra and Malaysia when testing for oil palm disease resistance by inoculating with *Ganoderma*. Earlier work by us led to introduction of shading also to DRC for screening for *Fusarium* resistance, as this pathogen is also inhibited or killed at high temperatures [H]. Specific forms of impact include:

1. A change of practice in the way organisations test for disease resistance:
Shading of seedling palms to maintain ambient soil temperatures has been introduced by various companies including LONSUM, Indonesia; FELDA/FASSB, Malaysia. *LONSUM* commented:
"Dr Cooper and his team made a discovery that has markedly improved our ability to inoculate and select for disease resistance to Ganoderma. Shading is now used routinely for nursery screening; their finding allowed development of a fast screening test; results correlate with long term field trials; Ganoderma threatens sustainability of S E. Asian oil palm industry; up to 87% of palms may be lost" [F].
FELDA stated:
"..650,000 ha of oil palm [is grown] in FELDA; BSR [*Ganoderma*] *results in estimated loss of USD 6.6 million p.a; following a discovery in Dr Cooper's laboratory we now use artificial shading routinely in resistance screening; shortens duration from 12 to 8 months; number of progenies tested increased significantly*" [F].

2. Progress towards sustainable development:
Efficient screening for resistance to *Ganoderma* is revealing resistant palm lines [I]. Fungicide use would cease, reducing pollution in environmentally sensitive tropical locations.

Dr Cooper's role and wider impact of oil palm pathology research
1. Research investment from and collaboration with *overseas* businesses (see funding, Section 3):
LONSUM (2002-2005) and FELDA (2011) funded research on *Ganoderma* and Agrinos (2010) on *Fusarium* control; collaboration is ongoing also with Sime Darby Ltd., another major player in palm oil production and with Applied Agricultural Resources (AAR) [G]. LONSUM is the 2nd largest public listed plantation company in Indonesia, with 81,000 ha dedicated to oil palm, sale of 26.4 million seeds and 2.3 million tonnes of palm fruit in 2011. FELDA, founded to resettle rural poor and organize smallholder farms, cultivates >650,000 ha of oil palms (approximately 18% of total

Malaysian oil palm area), has >600 employees and is the world's largest producer of certified, sustainable oil palm (Financial Times, 2012) [A].

2. Research investment and collaboration with government organisations:
The MPOB, the overarching advisory organisation [A], funded *Fusarium* research (2008-2012 and 2013), and Ministry of Higher Education *Ganoderma* research (2011-2014). Also MPOB sponsored field studies in South America (2012) to assess a major palm disease (*Phytophthora*) in the context of quarantine to prevent spread to South East Asia [G].

3. Invitation onto advisory panels:
FELDA and MPOB invited Dr Cooper to be a member of their international advisory panels (2011-2014) involving annual visits to Malaysia [G].

4. Knowledge transfer:
During 2009-2013 Dr Cooper delivered 18 invited seminars on *Fusarium* and/or *Ganoderma* control to *non-academic stake-holders*, including growers, companies and researchers in Malaysia, Indonesia, Ghana and Brazil, Two lectures were to audiences of >600; two talks were published as reviews in a professional journal for S E Asia [H]. Additionally, two workshops were held (Malaysia and Brazil) based around these invited presentations. The companies involved included FELDA, Sime Darby, Agrinos, Agropalma, Marborges and Denpasar; government organisations were MPOB, EMBRAPA, Oil Palm Research Institute (Ghana) and IOPR Indonesia [A].

5. Sources to corroborate the impact

(A) Company and organisation websites
Feronia: www.feronia.com/oil-palm/seed-farming/
LONSUM: www.londonsumatra.com/
FELDA: www.felda.net.my/ fssb
MPOB: www.mpob.gov.my/ http://www.palmoilhq.com/PalmOilNews/world%E2%80%99s-single-largest-palm-oil-event-
Agrinos: http://sea.agrinos.com/pt-br/node/529
CABI: http://www.cabi.org/?site=170&sid=1834&page=1019
Ghana Sumatra (CSIR-OPRI): http://www.ghanasumatra.com/products.php
IOPRI Yogyakarta: r4d.dfid.gov.uk/PDF/Outputs/CABI/Ganoderma-Diseases.pdf
Applied Agricultural Resources (AAR) www.aarsb.com.my
(B) Indonesian palm oil benefits: http://worldgrowth.org/site/wpcontent/uploads/2012/06/WG_ Indonesian_Palm_Oil_Benefits_Report-2_11.pdf
(C) Chung Gait Fee (2011). The Planter 87: 325-339.
(D) Corley R H V,Tinker P B (2003). *The Oil Palm 4th Edition*. Oxford: Blackwell Publishing.
(E) Patent: Cooper, R.M., Flood, J. and Mepsted, R. Disinfestation of oil palm seed. (1993) "Fungicide Treatment of Oil Palm Seeds" *GB PATENT 9300 142.8.* International (PCT).
(F) Testimonials from FELDA, LONSUM, Ghana Sumatra and CABI, UK
(G) Documents, e mail confirmations of: advisory panels; presentations; ongoing collaborations.
(H) Cooper, R. M., Flood, J., Rees, R. W. (2011). *Ganoderma boninense* in oil palm plantations: current thinking on epidemiology, resistance and pathology. *The Planter* 87, 515-526.
Cooper, R.M. (2011) Fusarium wilt of oil palm: a continuing threat to the Malaysian oil palm industry. *The Planter* 87, 409-418. (*Invited articles for this professional journal for SE Asia).*
(I) http://palmoilis.mpob.gov.my/publications/jopr2006sp-ms24.pdf.