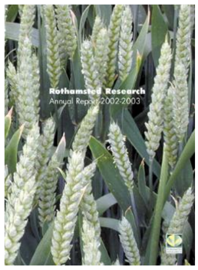
Rothamsted Research Annual Report 2002-2003



Full Table of Content

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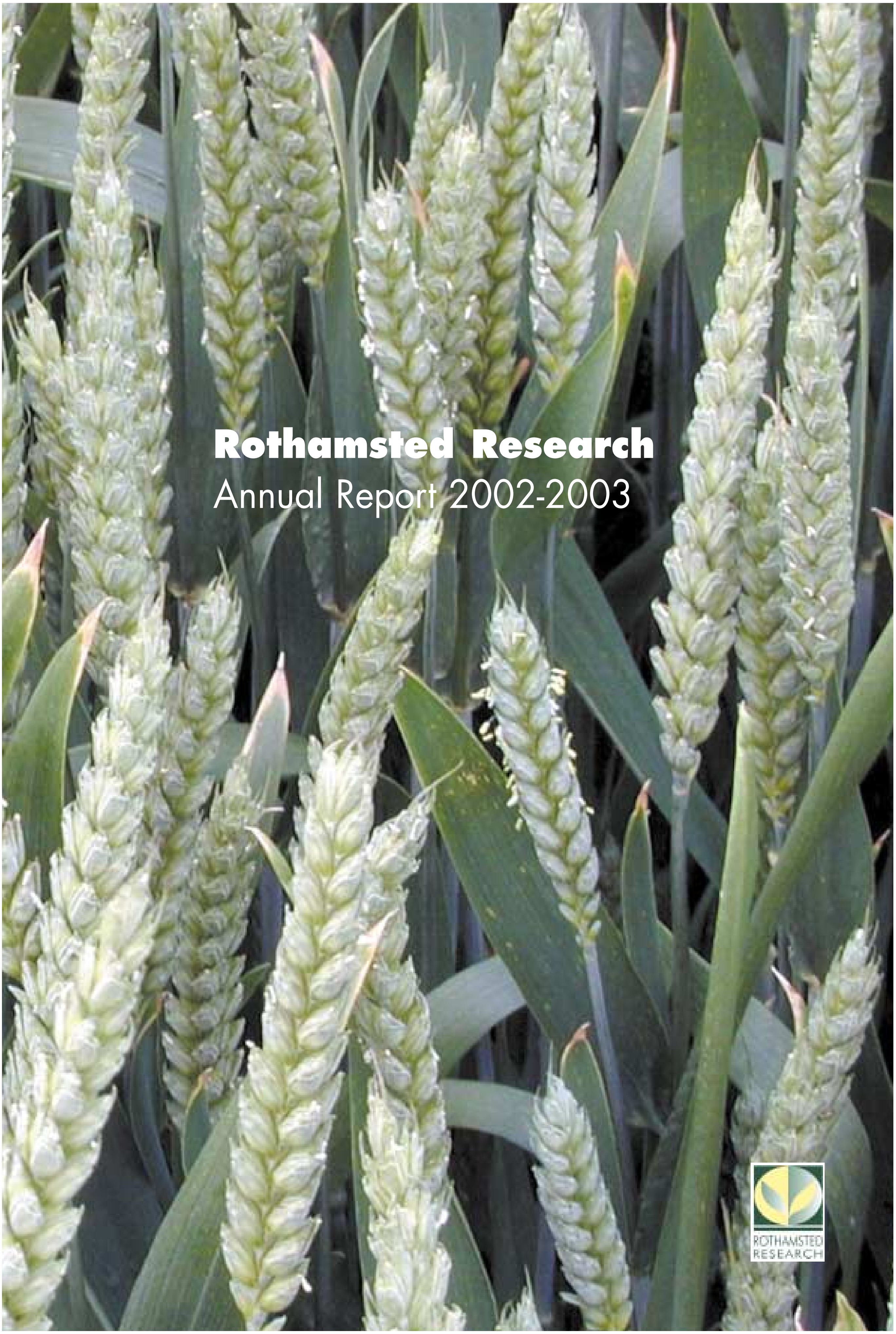

Rothamsted Research

Annual Report 2002-2003

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ROTHAMSTED RESEARCH

Rothamsted Research comprises laboratories
at Rothamsted and Broom's Barn and is
sponsored by the Biotechnology and
Biological Sciences Research Council.

CONTENTS

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FOREWORD

In July 2002, I announced that the newly restructured Institute would become known as "Rothamsted Research" with effect from 1 January 2003. This change heralds the completion of our spectacular new laboratory at Rothamsted, to be called the Centenary Building in commemoration of 100 years of research at Long Ashton Research Station. During 2003, those who fund and benefit from our research should start to see the gains resulting from collocation, within the Centenary Building, of researchers simultaneously relocating from Long Ashton (which now closes) and from old laboratories at Rothamsted, no longer fit for purpose. Restructuring has been a dominant preoccupation of the Institute for almost 4 years and, as it reaches a culmination, nobody should underestimate its impact on domestic and professional lives. I am grateful for the commitment and tolerance shown throughout by all those staff affected.

"Integrative Biology" is both a central theme of our primary sponsor (the Biotechnology and Biological Sciences Research Council) and an excellent descriptor of the way Rothamsted Research conceives and conducts its science. Indeed, multidisciplinary integration has been the primary driver of our restructuring. Our investigations at the molecular level are conducted to inform studies of cell biology that in turn help to explain the behaviour and performance of the whole organisms in response to their environment and as populations. In this context, you will find abundant evidence for the success of our integrative approach both in the content of this report and in the listing of our year's publications to be found at: http://www.rothamsted.ac.uk

Ian Crute

The newly restructured institute was showcased to funders and stakeholders at the Royal Society on 20th January

DIRECTOR'S INTRODUCTION

Rothamsted Research: a view of the future

2003 – a new laboratory and a new name

During 2002, I announced that the former Institute of Arable Crops Research would cease to exist as an entity and the name of our restructured organisation would be Rothamsted Research (formally abbreviated to RRes). Our new name conveys continuity with a past of which we are justly proud but also signals a landmark in the process of significant change on which we embarked over four years ago. Early in 2003, we "launched" Rothamsted Research during a successful event for our many stakeholders at the Royal Society in London.

The plan to amalgamate the research conducted at Long Ashton Research Station and Rothamsted Experimental Station was announced during 1999 and by May 2003 the transfer of more than 50 scientific staff from Long Ashton to Rothamsted will have been completed as will the occupancy of a spectacular new laboratory at Rothamsted. This new laboratory enables the close integration that modern multidisciplinary science demands and collocates those transferring from Long Ashton with colleagues moving from laboratories at Rothamsted which are no longer fit for purpose. The outcome is that all our work in plant, invertebrate and microbial biomolecular sciences will be housed together in state of the art facilities backed by excellent glasshouse, insect rearing, controlled environment, analytical chemistry and biological imaging capability. This development is a tangible manifestation of an enduring partnership between RRes, the Lawes Agricultural Trust, who own the Rothamsted site, and the BBSRC.

The Board of Directors of RRes have named the new laboratory the "Centenary Building" to mark the fact that 2003 coincides with 100 years of scientific research at Long Ashton (appropriately chronicled in a recent publication entitled: "Long Ashton Research Station: one hundred years of science in support of agriculture" edited by Anderson, Lenton and Shewry). The period of planning and construction of the Centenary Building also coincided with the centenary of the death of Rothamsted's founding fathers: Sir John Lawes and Sir Henry Gilbert.

Keith Goulding received the RASE medal for his contribution to soil science (left)

Three Rothamsted PhD students Lucy Gilliam, Richard Haslamand Andrew Downie exhibited their work in the House of Commons during Science week

Rothamsted Research – meeting the challenges of sustainable development

Agriculture and food production provide one of the most spectacular illustrations of the benefit that the acquisition of scientific knowledge can have on the well being of mankind. Just a few generations ago there was no part of the globe that was free from deprivation resulting from unpredictable food supply. Thanks to the application of science, we are, in Europe at least, confident of a predictable supply of sufficient, good quality, affordable food and Rothamsted has been centre-stage in this endeavour. However, today's context for land management in northern Europe is set by the inevitable expansion of the European Union, the globalisation of world trade, the expectations of an increasingly prosperous population, the strengthening green agenda and the increasing economic value accorded to land for purposes other than food production. Nevertheless, we should not forget that over 840 million people are undernourished and the population of the globe is set to rise from 6 billion to 9 billion by 2050. In the next 50 years, the world must produce at least 75% more food than it does at present to sustain the projected increase in population. We must reconcile the scientific agenda that is influenced by land management strategies in Europe with the requirements for land and food of the world's disadvantaged populations.

Science that provides an understanding and delivery of more sustainable production systems unifies what at first sight might seem disparate requirements of primary producers in the developed and developing world. Simply put, there is only one agenda. This agenda is for new knowledge, translated into new technology, to enable greater required productivity per unit area of land, in parallel with reductions in non-renewable inputs. The value that is placed on land for purposes other than food production, whether in Europe or elsewhere, means that there is no sound argument for cultivating more land than is absolutely necessary. This is regardless of whether the reason is to conserve the functional or aesthetic value of natural habitat or to create sought after man-made amenity. To avoid the requirement for more land to be devoted to food production there is a need for an intensification of science-based management as a means of achieving reductions in non-renewable inputs.

The classical Broadbalk winter wheat experiment at Rothamsted has generated data since 1843 and mirrors production in the UK. For about 100 years, yields from continuous wheat cultivation on plots receiving no inputs were between 1 and 1.5 tonnes per hectare. Over this same period it was clearly demonstrated that yields could be predictably doubled with inputs of farmyard manure or mineral fertilisers. Yields took-off in the 1960s with the introduction of semi-dwarf varieties, the

Box 1:

Ten attributes that define sustainable systems of land management

- substantially dependent on renewable inputs
- predictable output over many generations
- non-polluting
- profitable and socially acceptable
- conserves functional and aesthetic biodiversity
- conserves valued landscapes
- maximises resource use efficiency
- does not transfer problems elsewhere
- adverse changes are readily reversible
- responsive to changing requirements and constraints (e.g. population and climate)

'Chasing the High Flyers' exhibit on vertical radar studies was selected for the Royal Society summer science exhibition. It was also featured at the Tomorrow's World Roadshow and the Science museum

Box 2:

Drivers for science in support of sustainable management of agricultural land

- reduced reliance on fossil carbon inputs
- effective nutrient recycling (especially N, P and K)
- durable pest, disease and weed control less reliant on chemical synthesis
- characterisation and conservation of functional biodiversity
- crop genetic improvement for resource use efficiency
- definition and conservation of soil quality
- minimisation of diffuse pollution (air, water and soil)
- crops as "factories" and fossil carbon substitutes

deployment of genetic disease resistance, and the judicious use of herbicides, fungicides and insecticides. As a consequence of these advances, crops yielding 10 tonnes per hectare can be regularly achieved. These remarkable levels of output have been achieved for just one generation, and it is important to know whether they can be sustained indefinitely.

Sustainability means different things to different people and there are those who conclude the concept has generated more conflict than consensus. However, within RRes we have recently identified ten attributes that define sustainable systems (Box 1) along with the key drivers that provide the rationale for RRes science in support of sustainable land management and rural economies (Box 2). It is evident that some of the inputs that drive today's level of output are not truly sustainable. Agriculture is heavily dependent on fossil carbon inputs; pathogens evolve to overcome genes for resistance; weeds, pathogenic fungi and insects evolve resistance to agrochemicals. There are also legitimate questions about the economic and environmental impact of modern agricultural practice such as fertiliser usage. With a view to future generations, there is an urgent need for new, substitute technologies founded on sound science, that will in time replace inputs dependent on non-renewable resources.

As part of the Golden Jubilee celebrations we hosted the Jubilee Science Walk around the Rothamsted estate, attracting around 300 people


Rothamsted Research PhD student Symposium was held on 22-23 April 2002

Sustainable agriculture and the promise of integrative biology

At the start of the 21st century, there is a burgeoning of knowledge about how biological systems work. This explosion of information is being catalysed by both access to whole genome DNA sequences and a new productive synergy between the biological, physical and mathematical sciences. There is therefore a real cause for optimism that new products and practices will emerge from the knowledge-based revolution in the biosciences. This provides the backdrop for the BBSRC's recently published "Bioscience for Society - Ten-Year Vision: towards predictive biology" and its Strategic Plan to 2008: "World Class Bioscience".

The RRes research strategy reflects the BBSRC's commitment to research for sustainable agriculture and is closely aligned with the report from the Policy Commission on the Future of Farming and Food (Curry Commission) and Defra's response to it. The scientific and technological progress required to achieve more sustainable systems of land management is underpinned by a focus within both RRes and the BBSRC on the concept of integrative biology and the vision of a more predictive understanding than is possible at present.

The central importance of whole organism biology and the complex of interactions between organisms, is a hallmark of RRes science. However, to understand the biology of whole organisms requires integration of knowledge from the level of cells and molecules that draws on chemistry, genetics, biochemistry and molecular biology. The development of verifiable predictions based on large data sets and formalised in mathematical models is a feature of RRes science. One outcome consistently sought from RRes research is more accurate prediction about how complex systems behave and how best they can be managed for benefit.

In the context of integrative biology of relevance to sustainable agriculture, the scientific community now has access to the whole genomic sequence of several relevant organisms and the stage is set for knowledge derived from these data to play a significant part in achieving greater sustainability of agricultural systems. It is through knowledge from integrative biology that technologies will emerge that can substitute for present ones that are acknowledged as being unsustainable in the long term.

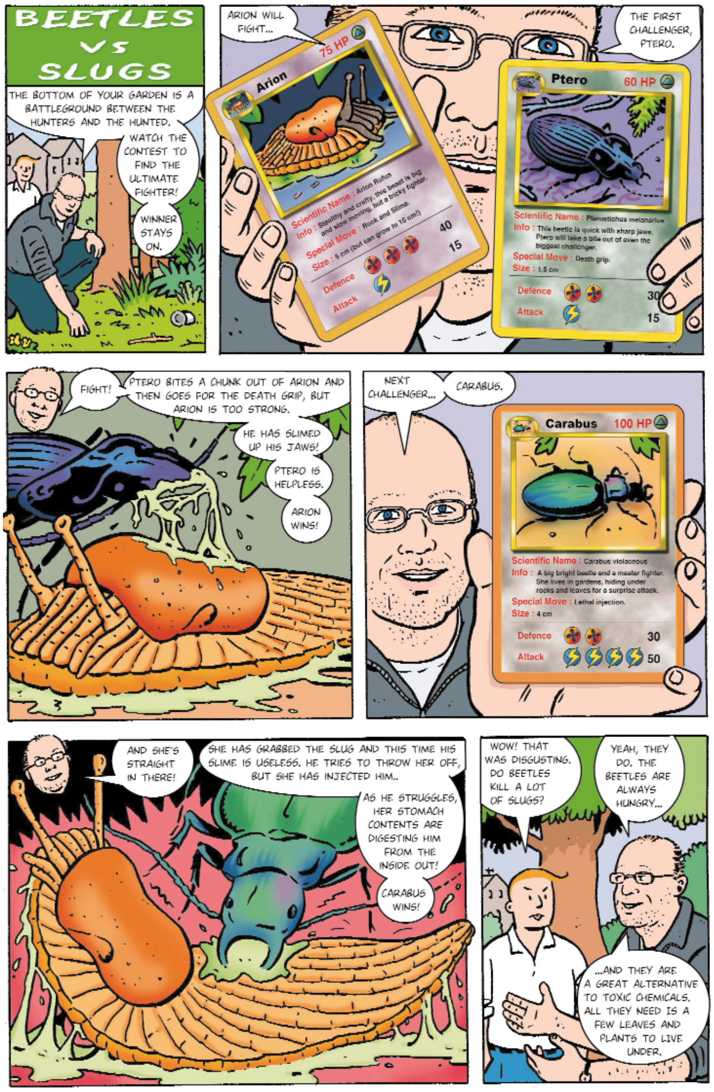
The future emphasis of RRes over the next decade will be the introduction of new sustainable practices based on high quality ecological and environmental sciences along with new sustainable products based on high quality biomolecular sciences. Our objective will be to contribute significantly to the implementation of "Best Practice".

RRes will be striving hard to understand and meet the changing requirements of its end user communities. The

Alastair McCartney receiving an honorary professorship from Professor Cheng Jian, President of the Anhui Academy of Agricultural Sciences, China. He also accepted an honorary professorship on behalf of Bruce Fitt. The awards recognised collaborative research between the Plant Pathogen Interactions Division and Anhui Academy of Agricultural Science

Rothamsted science was explained in cartoon format with help from a BBSRC grant.The cartoons were distributed free to schools and featured in BBC wildlife magazine

Rothamsted Research Association (formerly the Arable Research Institute Association) provides a vehicle for an active dialogue with the UK land management sector. Similarly, Rothamsted International enables our engagement with the International Development agenda. We expect to meet the needs of the EU and Defra in the formulation and implementation of policies of relevance to agriculture and land management and we expect our work to impact on both the production and supply sides of the food and non-food chains. In the context of sustainable development, RRes has a key strategic role to play in the coming years. We take this responsibility seriously as society confronts some enormous national and international challenges. Not all answers lie with science but, as in the past, science has a large part to play in achieving benefit and security for future generations. We have more opportunity now than ever before to harness biological knowledge for widespread benefit.



ROTHAMSTED RESEARCH

Mission and Structure

**The Mission of Rothamsted Research is:
To be a world leading scientific research establishment making significant contributions, nationally and internationally, to the management of agricultural land and the environment through innovations that lead to sustainable products and practices reducing reliance on non-renewable inputs.**

Rothamsted Research will accomplish its Mission by:

- Working with all stakeholders to achieve a shared vision of what can and should be achieved;
- Recruitment, retention, direction and motivation of talented scientists, other professionals and support staff;
- Provision of an efficiently managed and stimulating environment with access to first-class facilities;
- Concentrating on activities where an internationally competitive position has been or can be established;
- Forging mutually beneficial strategic alliances and collaborations;
- Operating communication mechanisms and establishing partnerships that ensure rapid and effective application of valuable new knowledge;
- Continuously renewing expertise in relevant disciplines;
- Ensuring that discoveries achieve practical impact as quickly and effectively as possible

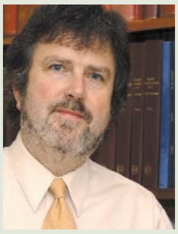
ROTHAMSTED RESEARCH

Six Research Divisions

CROP PERFORMANCE and IMPROVEMENT

Head of Division: Peter Shewry

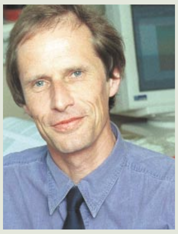
Mission: To improve crop productivity and quality by understanding and manipulating nutrient acquisition, primary and secondary metabolism, growth and development.



PLANT-PATHOGEN INTERACTIONS

Head of Division: John Lucas

Mission: To develop effective, durable, economic and environmentally sound strategies for the control of crop diseases through an improved understanding of the interactions between plants, pathogenic agents and the environment.



PLANT and INVERTEBRATE ECOLOGY

Head of Division: Ian Denholm

Mission: To understand the population dynamics and genetics of agricultural ecosystems and exploit chemistry and biodiversity to reduce the constraints on crop production and quality imposed by invertebrate pests and weeds.

BIOLOGICAL CHEMISTRY

Head of Division: John Pickett

Mission: To devise novel strategies for the management of pest populations through the identification and exploitation of naturally occurring semiochemicals that mediate pest behaviour and by understanding and countering pesticide resistance mechanisms together with knowledge of pesticide environmental fate.

AGRICULTURE and the ENVIRONMENT

Head of Division: Keith Goulding

Mission: To optimise crop yield and quality while protecting soils, water, the food chain and the global environment through an understanding of biogeochemical cycling and the ecology and remediation of soils.

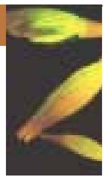
SUGAR BEET PRODUCTIVITY and IMPROVEMENT

Head of Division: John Pidgeon

Mission: To enhance productivity and profitability while minimising environmental impact of sugar beet cultivation through genetic improvement, mitigation of biotic and abiotic stresses and optimisation of production systems.

Genetic transformation is the integration of recombinant nucleic acid molecules into the genome of a target cell. It is a powerful tool in plant biology and is commonly used to study gene function, by over-expression or targeted silencing of specific sequences. However, a range of other applications is possible, including identification of genes and promoters by tagging. Unlike *Arabidopsis*, for which germ-line transformation is available, wheat can only be transformed via delicate tissue culture procedures involving the regeneration of plants via somatic embryogenesis and until recently has proved recalcitrant to transformation by *Agrobacterium*.

ROTHAMSTED RESEARCH



Genetic transformation and promoter tagging in wheat

Huw D Jones

Wheat florets expressing GFP (green fluorescent protein).(left)

DNA-delivery via biolistics or *Agrobacterium*

Since the first reports of wheat transformation in the early 1990s, robust protocols using biolistics to introduce DNA into regenerable scutella tissues have been developed and are now routine in several laboratories world-wide. We have used optimised protocols based on biolistics to produce over six hundred transgenic lines in thirty wheat genotypes, including elite cultivars grown in the UK. These lines have proved to be uniquely useful in the characterisation of several important promoters and in the study of the role of a wide range of proteins including a suite of high molecular weight glutenin subunits and the gibberellin 2oxidase enzyme. However, plants produced by this method tend to have a high transgene copy number, occasionally with multiple rearrangements, and in some cases this can complicate the analysis of transgene expression. The soil bacterium *Agrobacterium tumefaciens* (the causative agent of crown gall disease) is known to deliver low copy number T-DNA insertions and is now the transformation method of choice for most other plant species. Wheat is normally outside the host range of *Agrobacterium*, but we have successfully optimised a range of variables affecting T-DNA delivery and regeneration, and produced transgenic wheat plants using this approach. Initial analysis of copy number and transgene segregation in these lines indicates that the majority display simple, low copy integration patterns and a 3:1 inheritance ratio (Figure 1).

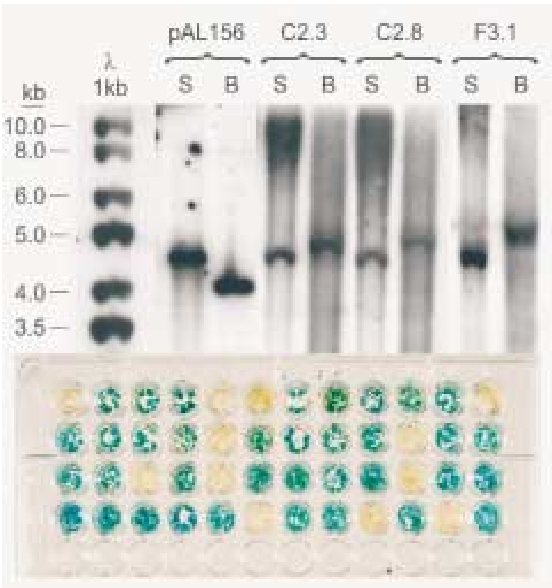


Figure 1. Southern blot of three plants (C2.3, C2.8 & F3.1) transformed via agrobacterium showing low copy number, simple integration patterns (top). GUS assay of T_1 progeny plants showing a 3:1 segregation of transgene expression (bottom)

Transgene integration

The precise order of the molecular events leading to the stable integration of a transgene into the host plant genome is unclear. However, it appears that regardless of the method of DNA-delivery, genetic transformation involves double-stranded illegitimate recombination at one or more loci, utilising the cell's nuclear repair machinery. The moment of integration probably coincides with a DNA metabolic event such as replication or transcription. Some *in situ* hybridisation data suggest that physical integration occurs at random within and between plant chromosomes. However other analyses demonstrate a preference for distal chromosomal locations and actively transcribed regions of the plant genome with the possibility that native plant genes are disrupted in the process. We have used fluorescence *in situ* hybridisation (FISH) to study the distribution of transgene insertions in wheat. Initial analysis reveals no preference for particular wheat chromosomes but a bias towards the telomers (Figure 2).

Promoter tagging

Although the nuclear genome of all cells in a genetically modified plant will contain transgene copies, the regulatory promoter sequences upstream of the coding region will dictate when and where in the plant the transgene will be expressed. One of the bottlenecks to the application of plant transformation technologies is the lack of well-characterised tissue-specific, developmentally regulated and environmentally induced promoters that can be matched with specific coding sequences to drive expression in particular tissues or developmental stages. We are using two approaches to overcome this bottleneck. Firstly to use markers such as green fluorescent protein (GFP) or beta-glucuronidase (GUS) to

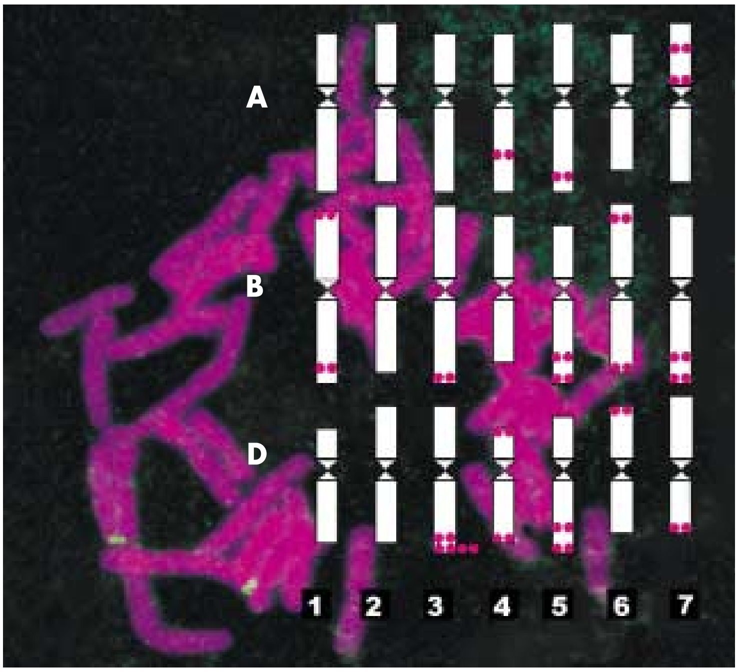


Figure 2. Fluorescence *in situ* hybridisation (FISH) of transgenes in wheat chromosomes (background). Representation of integration sites from over 20 independent lines analysed by FISH showing bias towards telomers (foreground).

(Work done by Jean Jacquet, a BBSRC-CASE student in collaboration with Mark Tester, Cambridge University and Peter Jacks, Monsanto UK) characterise known promoter sequences in transgenic wheat. More than ten constitutive or tissue-specific promoter sequences are currently being analysed in wheat transgenics (Figure 3). In a second approach, we are using promoter tagging to identify novel regulatory sequences. We have shown previously that transforming with promoterless marker genes can generate novel, specific, heritable expression patterns (Figure 4). However, the difficulty in generating sufficiently high numbers of independent transgenic lines in wheat limits this approach. In collaboration with Christine Foyer and Gabriela Pastori we have exploited the ability of the maize Activator/Dissociation (AcDs) transposon to jump a promoterless marker gene around the wheat genome. By generating a limited number of Ac and Ds parental lines and crossing them, we have made a large number of plants each containing both the Ac and Ds insertions. We have already demonstrated by sequencing that the Ds elements in progeny plants of several Ac x Ds crosses do undergo transposition and we believe that transposon-mediated promoter tagging in wheat is feasible.

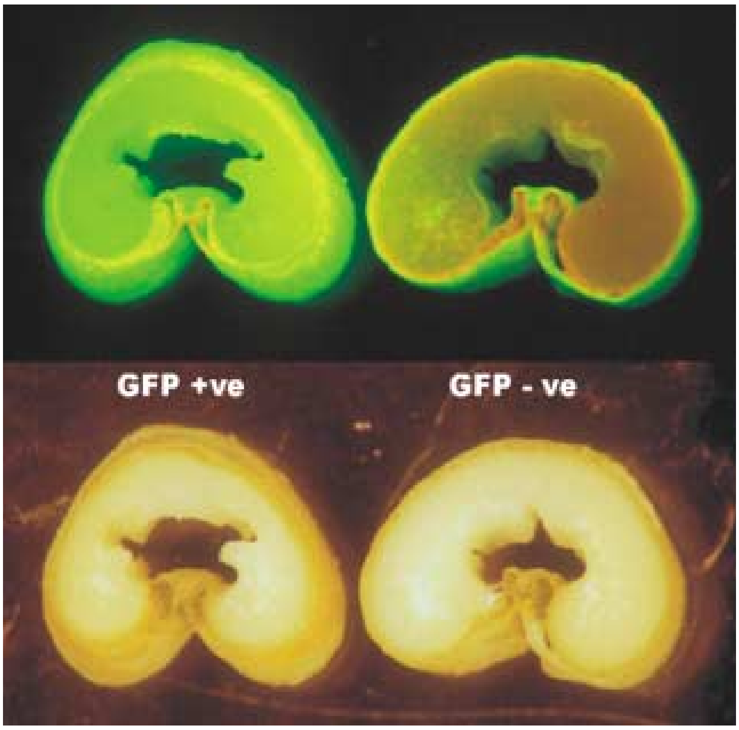
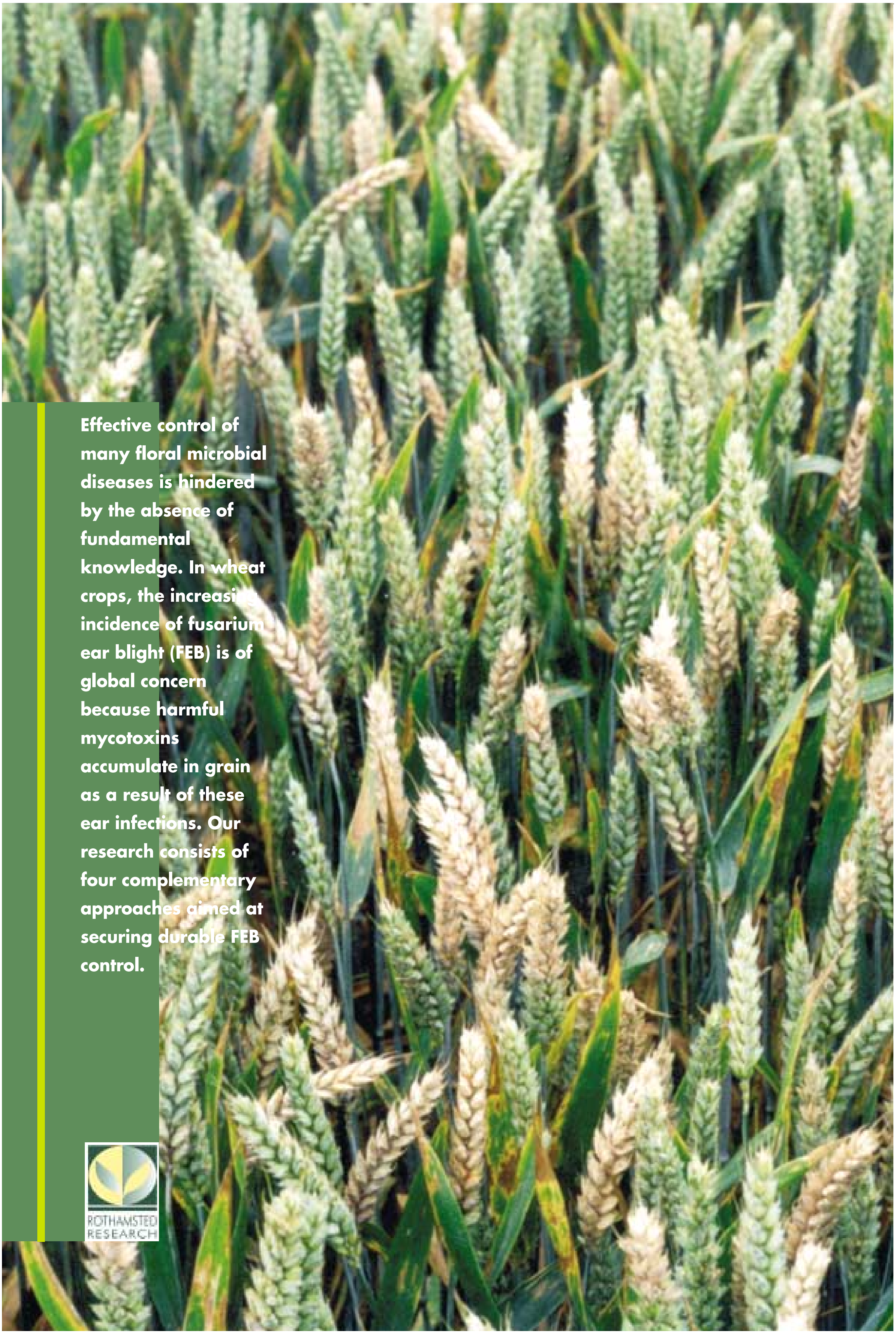


Figure 3. GFP expression in immature wheat seeds driven by the rice actin promoter visualised under UV light (top). Same seeds under white light (bottom)

Exploitation

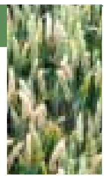
The output from whole genome and expressed gene (EST) sequencing projects continues to increase exponentially but annotation to ascribe gene function lags significantly behind. Genetic transformation is already one of the key methods used to investigate or validate gene function and, together with associated high-throughput techniques such as transient expression, is set to be an important tool for functional genomics. The hexaploid status of bread wheat and the fact that it has many unique structural and physiological features complicates the use of model species to accurately predict gene function in this important food and feed crop. Thus, the ability to over-express, knockout and tag specific gene sequences directly in a specific wheat variety is a compelling technology in many areas of wheat research. We are currently the only publicly funded laboratory in the UK capable of agrobacterium-mediated wheat transformation and Rothamsted Research is in a unique position to exploit this technology for research to benefit UK and world agriculture.

Figure 4. Random insertion of a promoterless GUS gene results in anther-specific expression patterns in immature inflorescence



Effective control of many floral microbial diseases is hindered by the absence of fundamental knowledge. In wheat crops, the increasing incidence of fusarium ear blight (FEB) is of global concern because harmful mycotoxins accumulate in grain as a result of these ear infections. Our research consists of four complementary approaches aimed at securing durable FEB control.

ROTHAMSTED RESEARCH



Strategies for controlling *Fusarium* ear blight disease, an emerging threat to UK cereal crops

Kim Hammond-Kosack, Geoff Bateman, Martin Urban, William Dawson and Arsalan Daudi

Figure 1. A UK wheat crop exhibiting severe fusarium ear blight symptoms 6 weeks prior to harvest. (left)

Worldwide, *Fusarium* ear blight (FEB) infections of cereal crops cause considerable losses in grain quality and safety (http://www.scabusa.org). *Fusarium* infections in UK wheat crops have been steadily increasing since the early 1990s, probably due to changes in crop rotations, the introduction of maize into regions where previously only wheat was grown, the use of low/minimum tillage practices and climate change. The two main causative agents are the fungal species, *F. culmorum* and increasingly *F. graminearum* (teleomorph stage *Gibberella zeae*) (Figure 1) (http://www.csl.gov.uk/resdev/AH/PDCP/epid/fusarium/). The disease is primarily monocyclic, with ear infections occurring when moist conditions prevail at anthesis and inoculum is available.

Grain harvested from *Fusarium*-infected ears is frequently of poorer quality (Figure 2) and contaminated with mycotoxins, including the highly toxic trichothecene mycotoxins, such as deoxynivalenol (DON). Mycotoxin contamination of grain presents a serious health risk to humans and animals, and the EU is soon to legislate on the permitted DON levels in food and feed. The brewing industry already has zero tolerance of *Fusarium* mycelium and mycotoxins in cereal grain because these adversely affect the fermentation process. The cellular target site for DON mycotoxin is the peptidyl transferase protein in the ribosome. DON-binding inhibits protein synthesis in eukaryotic cells.

Figure 2. grain recovered from fusarium infected wheat ears is often smaller and shrivelled (right)

Our research consists of four complementary approaches aimed at securing durable FEB control. These are:
1) increasing our understanding of the epidemiology of the disease under UK conditions;
2) the identification of promising biocontrol species that can restrict infection of wheat ears;
3) defining the *Fusarium* genes required to cause disease and regulate mycotoxin production; and
4) the characterisation of natural wheat resistance mechanisms that can lower mycotoxin levels without compromising grain quality. We have recently shown that *Arabidopsis* floral tissue can be infected by the same *Fusarium* species that attack wheat ears. This model system will be exploited via comparative molecular genetic studies to provide greater insight into FEB.

Understanding the disease epidemiology

The *Fusarium* species that infect cereals exist saprophytically, on dead crop debris, but can also become pathogenic, causing visible disease symptoms on stem bases and cereal ears. A symptomless state on the surfaces of roots or leaves can also occur. Our epidemiological research has focused initially on understanding the main sources of fungal inoculum and the route of dispersal to the wheat ear. *F. culmorum* population size in soil

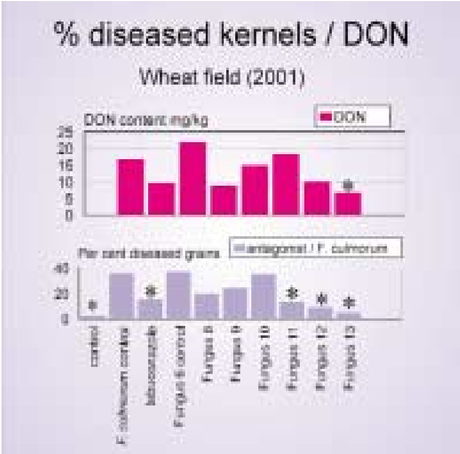


Figure 3. Some antagonist fungal species can control *Fusarium* ear blight as effectively as a conventional fungicide treatment. *Shows significant differences from *F. culmorum* only control

varies erratically, but is greatest after cereal crops and particularly after straw incorporation. A rapid build up in inoculum levels can occur during the summer. Inoculum of *F. culmorum* arises primarily from infested debris within the crop lying on the soil surface. Therefore, burial by ploughing-in should remove such an inoculum source.

Control of *F. graminearum* may be more problematic, because sexually produced ascospores released from infested crop debris are air-borne and potentially dispersed over longer distances. Other researchers have shown that maize is an important source of inoculum for infection of wheat by *F. graminearum* grown in the same or nearby rotations. This situation is likely to occur in the UK, and we have found *F. graminearum* infections to be associated with maize crops. The timing of ascospore production under UK conditions has not yet been determined.

The potential of biological control

FEB has recently been the focus of intensive searches for agents of biological control, particularly in the USA where research has concentrated on strains of antagonistic bacteria. A project funded by the EU aims to prevent *Fusarium* mycotoxins entering the human and animal food chain. It includes the investigation of biological agents as an approach to pre-harvest control.

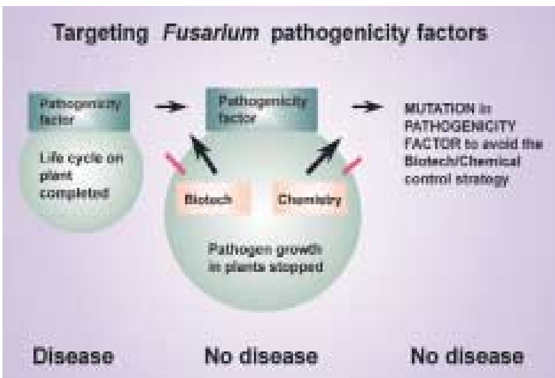
With partners in PRI (Plant Research International, Wageningen, The Netherlands), ISPAVE (Institute of Plant Protection, Rome, Italy) and EELA (National Veterinary and Food Research Institute, Helsinki, Finland), (www.mycotoxin-prevention.com), our aims were to attempt biocontrol at two vulnerable stages in the natural disease cycle: the production of inoculum (*Fusarium* spores) on crop debris and the ear infection phase. At RRes, we have concentrated on the latter objective. Strains of competitive fungi were chosen as the most promising option and were selected from collections of fungi isolated from various European cereal crops. Candidate strains, identified in semi *in vitro* and glasshouse screens, were tested for efficacy in field trials (Figure 3). Interestingly, different fungal isolates provided the greatest protection at each of the two key stages in the disease cycle where biocontrol was attempted.

Reducing ear infections has proven particularly amenable to biocontrol probably because the susceptible plant tissue, mainly the anthers and young florets, has only recently emerged from the flag leaf and so is substantially free of an established natural surface microbiota. Also, biocontrol is only required for the first 2 weeks after the onset of flowering, whereupon the maturing cereal ear becomes naturally resistant to infection. In the field trials, the best competitors were strains of non-pathogenic *Fusarium* spp. These treatments controlled both ear blight symptoms and mycotoxin production as effectively as a standard fungicide such as tebuconazole. Effective control with the same fungal species was achieved in wheat, barley and oats crops when the antagonist was applied before the pathogen. Various biocontrol fungi are currently being evaluated for their commercial potential.

Targeting *Fusarium* pathogenicity factors

This work is based on the premise that a pathogen mutation that circumvented the effects of an effective fungicide or a transgenic antifungal protein delivered by plant cells would be due to production of a variant pathogenicity factor or loss of such a factor. The suggestion is that such changes would have an effect on the mutant's fitness and ability to cause severe disease

Figure 4. Pathogenicity factors required to cause plant disease are excellent potential cellular targets for disease control



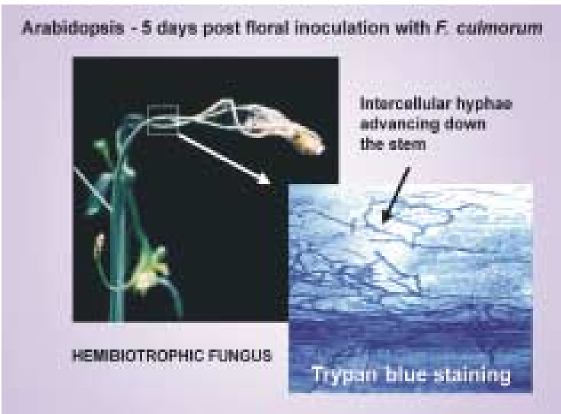


Figure 5. Cereal-attacking *Fusarium* species also cause a floral disease on *Arabidopsis thaliana*, a model non-cereal species

(Figure 4). Hence, the identification of fungal pathogenicity factors provides a target for discovery of novel approaches to achieve durable disease control.

Molecular genetic analysis of the FEB infection process is still fragmentary and understanding is being sought of the *Fusarium* genes required for fungal penetration, cereal ear colonisation and spore formation. It is known that DON production is not essential for *F. graminearum* to cause disease in wheat ears. Our laboratory and others have recently demonstrated that two distinct Mitogen Activated Protein Kinases (MAPKs) Map1 and Mgv1, are independently required for infection and subsequent spread within the wheat ear. In *Saccharomyces cerevisae* (yeast) the homologous protein to Map1 is Fus3/Kss1 which controls the pheromone response leading to mating, whilst the homologue in yeast to Mgv1 is Slt2 which controls cell integrity. In several other phytopathogenic fungal species, proteins sharing homology with Map1 were also found to be essential for plant penetration and/or invasive growth *in planta*. Collectively, these MAPK results suggest the existence of an ancient conserved core signalling mechanism that controls fungal pathogenicity. By targeting this MAPK pathway the control of multiple plant diseases may be achievable.

The resources and techniques available to undertake a large scale exploration of *Fusarium* gene function include the complete *F. graminearum* genome sequence (Whitehead Institute, Cambridge, USA) (http://www-genome.wi.mit.edu/annotation/fungi/fusarium/), various libraries of expressed sequence tags (ESTs) (http://cogeme.ex.ac.uk) and efficient transformation systems to create specific gene knockouts within 4-6 weeks.

Our current research aims to define all the components of the Map1 kinase signalling cascade and identify the downstream cellular targets. In addition, we are undertaking a genetic screen involving random plasmid insertion to isolate other *Fusarium* genes required for wheat ear pathogenicity and *in planta* induced DON mycotoxin production.

Exploiting natural resistance sources and mechanisms in various plants to achieve low DON mycotoxin levels in grain

Two main types of natural resistance to FEB are known in wheat. Type I resistance reduces initial infection incidence but its genetic basis is unknown. Type II resistance reduces the rate of hyphal spread within the ear tissue and is conferred by multiple unlinked loci. Currently, various sources of Type II resistance are being introgressed by breeders into well-adapted genetic backgrounds using marker-assisted approaches. However, this Type II resistance only reduces, but does not eliminate, mycotoxin contamination of grain.

We are attempting to determine which resistant wheat cultivars reduce mycotoxin production and to identify regions of the wheat genome that confer low mycotoxin accumulation. To assist in this research, genetically modified *Fusarium* strains in combination with biochemical analyses are being used to define the exact temporal and spatial patterns of DON biosynthesis in the visibly infected and non-infected parts of the wheat ear. In collaboration with the Crop Performance and Improvement Division, we are also undertaking research to ensure the most promising resistance sources do not adversely affect grain quality.

Recently, we have demonstrated that both *F. culmorum* and *F. graminearum* can infect *Arabidopsis* floral tissue and cause disease symptoms (Figure 5). During these floral infections DON synthesis also occurs. Genetic studies involving a range of *Arabidopsis* mutant lines are being used to define the signalling components controlling plant defence in floral tissue and also *in planta* induction of DON synthesis. Comparative molecular genetic experiments are also being undertaken to ensure that the key findings in the *Arabidopsis* model are relevant to the disease in the economically important cereal crops.

Activating defence mechanisms and other useful traits in crop plants by means of benign chemical signals offers a new approach to pest control and other aspects of plant production. We have recently shown that the common plant volatile *cis*-jasmone can activate plants to become less attractive to herbivorous pests, and more attractive to pest natural enemies such as parasitic wasps. We have now demonstrated use of *cis*-jasmone in the field to reduce populations of cereal aphids. This opens up other practical and scientific prospects for using *cis*-jasmone as a plant activator.

ROTHAMSTED RESEARCH

Developing plant activators for the field

Toby J Bruce, John A Pickett and Lesley E Smart

The aphid parasitoid, *Aphidius ervi*, attacking the cereal aphid, *Sitobion avenae.* (inset left)

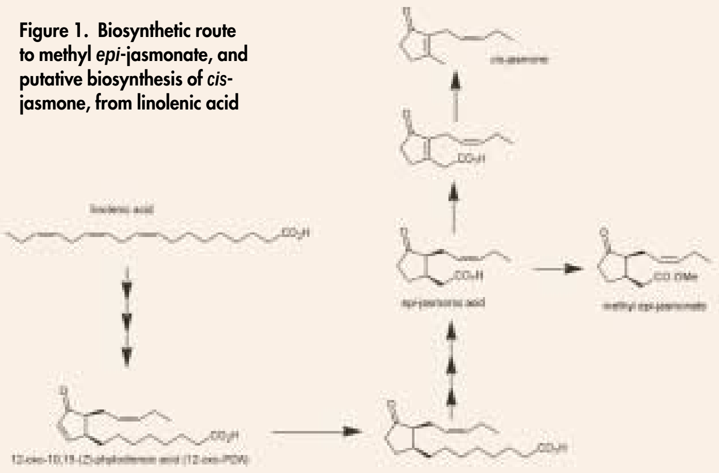
Background

The so-called "plant activators" that have been developed thus far by industry are non-volatile, persistent synthetic organic compounds. However, the natural products that provided the lead for these synthetic molecules act externally to the plant and often involve volatile products such as methyl salicylate and methyl jasmonate. *Cis*-Jasmone, although related biosynthetically to methyl jasmonate, had, until our recent work, been overlooked as a potential activator of plant defence.

Methyl jasmonate is formed initially as the *epi*-jasmonate isomer by oxidation and cyclisation of linolenic acid via 12-oxo-PDA (Figure 1). This biosynthetic pathway can be activated during damage caused by herbivory and other biotic agents, or by mechanical wounding. Methylation of the *epi*-jasmonic acid produces the volatile methyl ester, which can be emitted from the plant and used by animals searching for damaged plants (either because they wish to feed on the plant or on other animals feeding on the plant). Methyl jasmonate released from the essential oil of plants such as the sage brush, *Artemisia tridentata*, or from commercial sources, has been used to stimulate elevated defence responses in plants. For example, we have previously released methyl jasmonate above oilseed rape plants to enhance production of certain defensive glucosinolates.

Recently, we encountered *cis*-jasmone as an aphid repellent, and investigated it because of its relationship to methyl jasmonate (Figure 1). In these studies, we showed that two different aphid predators, a ladybird, and the parasitoid wasp *Aphidius ervi*, were attracted by *cis*-jasmone. This work was conducted initially on the bean plant, *Vicia faba*. We tested the hypothesis that *cis*-jasmone alters plant metabolism such that the plant becomes less attractive to herbivores and more attractive to parasitic wasps (Figure 2). Chemical analysis showed that *cis*-jasmone was rapidly taken up by the bean plants. After 24 hours, none could

Figure 1. Biosynthetic route to methyl *epi*-jasmonate, and putative biosynthesis of *cis*-jasmone, from linolenic acid



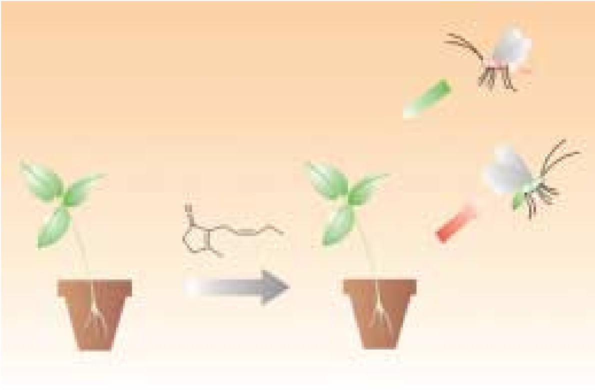


Figure 2. Plants placed in air containing a small amount of the volatile plant-derived chemical *cis*-jasmone can become less attractive to herbivores, e.g. aphids, and more attractive to beneficial insects such as aphid parasitoids

Table 1. Development of *Sitobion avenae* on treated wheat seedlings

	Treatment			
	Ethylan BV	*cis* -Jasmone	S.E.D.	*P* value
7 day wt.	0.461 a	0.329 b	0.0371	<0.001
MRGR[1]	0.362 a	0.302 b	0.015	<0.001
D[2]	11.53	11.90	0.231	0.113
Fd[3]	39.82	35.65	1.589	0.068
r_m[4]	0.237 a	0.223 b	0.005	0.013

[illegible]

be detected, either in the air above the plant, from which the *cis*-jasmone had been absorbed, or on the plant surface itself. The plants were retained for another 24 hours to ensure that no *cis*-jasmone remained and were then tested in a wind tunnel, and found to be significantly more attractive to the aphid parasitoid *A. ervi*.

From beans to cereals

In behavioural tests using a Pettersson olfactometer, *cis*-jasmone was highly repellent, even at low levels, to the cereal aphid *Sitobion avenae*. Winter wheat seedlings treated with low levels of *cis*-jasmone were investigated in field simulation experiments. Large numbers of *S. avenae* were released downwind of a tray of either *cis*-jasmone treated or control wheat seedlings in no-choice tests. After 24 hours, the proportion of *S. avenae* settling on the plants had been significantly reduced, from a mean of 60% on control plants to 38% on treated plants (P = 0.012). However, the time spent foraging by the parasitoid *A. ervi* on *cis*-jasmone treated wheat seedlings was significantly increased, from 6.6 minutes on control plants to an average of 17.6 minutes on the treated plants (P = 0.045). We also noted a phenomenon not observed with bean plants; the intrinsic rate of aphid population increase in repeated experiments was significantly reduced on *cis*-jasmone treated plants (Table 1).

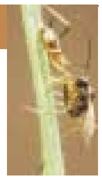
Field trials on winter wheat

Cis-jasmone was formulated with the non-ionic surfactant Ethylan BV, and applied by spraying the emulsion through a hydraulic nozzle (Figure 3).

Successful reductions in aphid populations have now been obtained for four seasons. Results from a representative season are given in Figure 4. The principle of using *cis*-jasmone as a plant activator in this way is clearly demonstrated by these field trials. The overall effect on aphid populations may be due to a combination of reduced settling and slower population development. The approach of applying an aqueous emulsion is possible, even for a highly volatile compound such as *cis*-jasmone, since the effect clearly persists after the initial contact. This also means that the dose received by the plants is substantially lower than the applied field rate. Indeed, further studies will be made on improving the application of materials such as *cis*-jasmone, so that a higher activity level than implied here can be exploited.

In the earlier studies with beans, it was noted that the release of the parasitoid foraging stimulant (E)-ocimene, induced by *cis*-jasmone, persisted for over 8 days, whereas the same induction by methyl jasmonate only lasted for the first 48 hours after exposure. Induction of

Figure 3. Application of *cis*-jasmone using a hydraulic spray boom in field plot trials



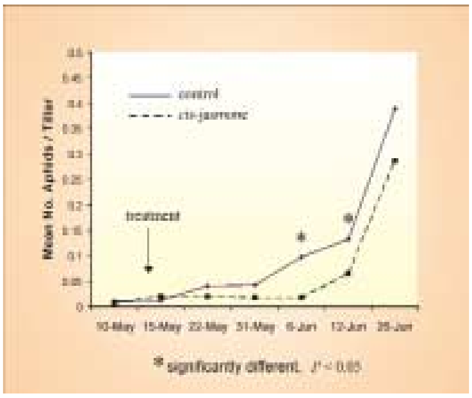


Table 2. Mean proportion of *Rhopalosiphum padi*, in no-choice test, settled on barley exposed to solutions containing *Elytrigia repens* compounds

Treatment	Proportion settled: Treated	Control	P
E. repens root exudate	0.67	0.86	<0.01
Mixture*	0.72	0.84	<0.001
Carboline (0.1 mg/ml)	0.62	0.89	<0.0001

*Mixture = hydroxytryptophan, hydroxytryptophan hydrate, indoleacetic acid, carboline (1, 1, 1, 0.2 mg/ml respectively)

Figure 4. Field results of treating winter wheat with an emulsifiable concentration of *cis*-jasmone in May with statistically significant reduction in aphid counts in June

wheat plants with *cis*-jasmone also caused an increase in release of (*E*)-ocimene. It was observed that foraging *A. ervi* spent significantly longer on treated wheat plants in the laboratory, resulting in more aphid mummies being formed. However, in field experiments, natural populations of parasitoids were too low to observe statistically significant effects on numbers of aphid mummies.

Opportunities for identifying further plant activators

In collaboration with the Swedish University of Agricultural Sciences at Uppsala, it has been shown that certain plant species can release chemicals that stimulate defence in neighbouring plants, even without the initial plant being damaged. These plants include thistle, *Cirsium* spp., and couch grass, *Elytrigia repens*, neither of which would receive favour from farmers as an intercrop and source of plant-activating chemistry. However, it was also found that certain cultivars of barley could stimulate the defences of other cultivars when grown in close proximity. So far, a number of volatile compounds have been identified which contribute to the induction of defence, but none are as active or persistent as *cis*-jasmone. Some of these interactions, as well as taking place through aerial contact, can involve communication via the rhizosphere. Couch grass, grown adjacent to barley plants, can significantly reduce aphid colonisation of the barley plants, where there is contact through the rhizosphere. A carboline, 6-hydroxy-tetrahydro-β-carboline-3-carboxylic acid, one of the compounds exuded from the roots of couch grass, has been shown to account for a substantial part of this effect (Table 2). We have now made a larger scale synthesis of the carboline, for field trials here and with our collaborators at Uppsala.

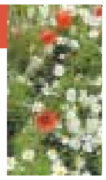
Exploitation

Although the results obtained in these field trials would not compete in terms of efficacy with broad-spectrum eradicant pesticides, the effect of *cis*-jasmone could be exploited by selecting cultivars that are genetically particularly responsive to defence induction by this signal molecule. Indeed, such traits could be bred into plants as a new strategy for exploiting plant activators in crop protection. Also, if the mechanism by which the persistent effect induced by *cis*-jasmone were better understood, alternative strategies to exploit this knowledge could be envisaged. There are reports in the literature that the putative biosynthetic pathway (Figure 1) allows the plant to regulate the effects of activity through a volatile sink (*cis*-jasmone), without there being a role for this component of the pathway. The different context of our discoveries allowed patenting and commercialisation of *cis*-jasmone as a plant activator.

It has been demonstrated that *cis*-jasmone treated *Arabidopsis thaliana* is less attractive to aphids. Johnathan Napier and Michaela Matthes of the Crop Performance and Improvement Division have demonstrated the up regulation of a specific set of genes, different from those affected by methyl jasmonate. These genes are involved in various functions including the metabolism of 12-oxo-PDA (Figure 1). It is hoped that these studies will enable elucidation of the mechanisms by which *cis*-jasmone upregulates genes involved in the biosynthesis of other volatile signals as well as the physiological effects, which reduce the development of pest insects. Promoter sequences that are responsive to *cis*-jasmone have been identified and could provide the means of activating other valuable biosynthetic pathways such as those determining drought tolerance, nutritional composition or crop development.

Research into weed population dynamics contribute to our understanding of weed behaviour. Studies of the responses of weeds to environmental stochasticity and of the physiological basis for differences in such responses between weed species are forming the basis for predictive, computer-based, systems of weed management. Such systems are taking into account the dual role of weeds in the arable environment as competitors with the crop and valuable contributors to biodiversity and food webs.

ROTHAMSTED RESEARCH



Weed population dynamics and its role in developing ecologically sustainable management systems

Peter J W Lutman, Laurence R Benjamin, John W Cussans, Jonathan Storkey

Typical annual weeds of winter cereals (*Papaver rhoeas*, *Tripleurospermum inodorum*.) (left)

Yield losses from weeds on the "classical" Broadbalk winter wheat experiment (Figure 1) show that as the time from a fallow year (when no crop is grown and full weed control is possible) increases, crop yield loss also increases, as a result of the population expansion of weeds. These data also reveal the level of variability that occurs in these natural processes. Crop yield loss varies from 0% to nearly 40% in the years immediately following fallow when weed population levels are at their lowest. These data illustrate two important principles. Firstly, that an understanding of the population dynamics of weeds is central to any attempt to understand and predict their behaviour and, secondly, that the variability that can occur in weed behaviour must be incorporated into the predictive process.

Population dynamics

Research into the population dynamics of noxious arable weeds such as black-grass (*Alopecurus myosuroides*), wild-oat (*Avena fatua*) and cleavers (*Galium aparine*) was in vogue ten years or more ago. Stephen Moss at Rothamsted devised a model for *A. myosuroides* that created the basic framework from which to explore the effects of changed management on populations (Figure 2). The emphasis has now changed, as developments in computer-based decision support systems have provided an opportunity to exploit these studies far more effectively in the promotion of economically sound weed control decisions. These tools were initially designed to explore methods of effective weed control, but they now have a role in designing environmentally targeted weed management systems, aimed at

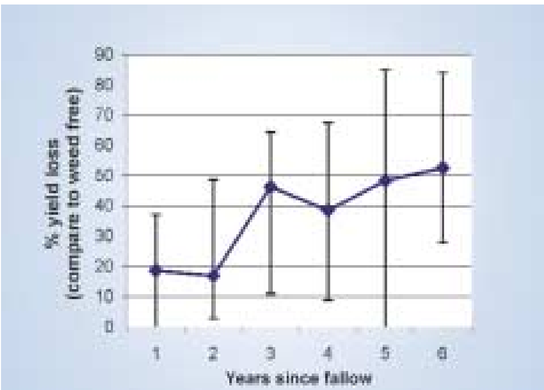


Figure 1. The impact of the number of years since a fallow on winter wheat yield loss due to weeds on the Broadbalk experiment (vertical bars show the range of responses)

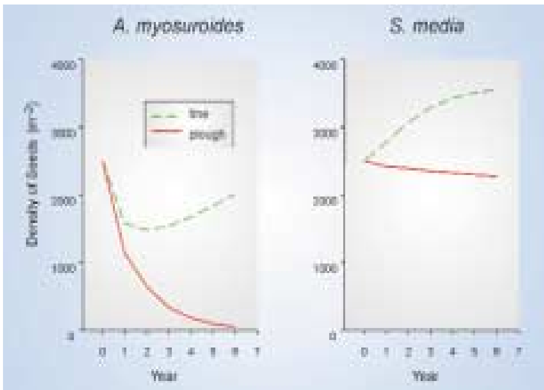


Figure 2. Prediction of the effect of ploughing and tine cultivation every year of a 6-year rotation on the density of seeds in the soil and in the seedbank for *A. myosuroides* and *S. media* assuming 95% kill of plants by the herbicides

Weed species	No. of associated insect species	Importance in bird diets	Competitive indices +
Avena fatua	<10		5.0
Alopecurus myosuroides	<10		12.5
Galium aparine	30		1.7
Sinapis arvensis	38	**	12.5
Tripleurospermum inodorum	30		12.5
Stellaria media	70	***	25
Poa annua	52	**	50
Senecio vulgaris	47	**	83
Cerastium fontanum	22	**	(25)
Veronica persica	<10		62.5
Viola arvensis	<10	**	200
Chenopodium album	30	***	(25)
Polygonum aviculare	60	***	50
Sonchus arvensis	28	*	(50)
Rumex obtusifolius	78	**	7

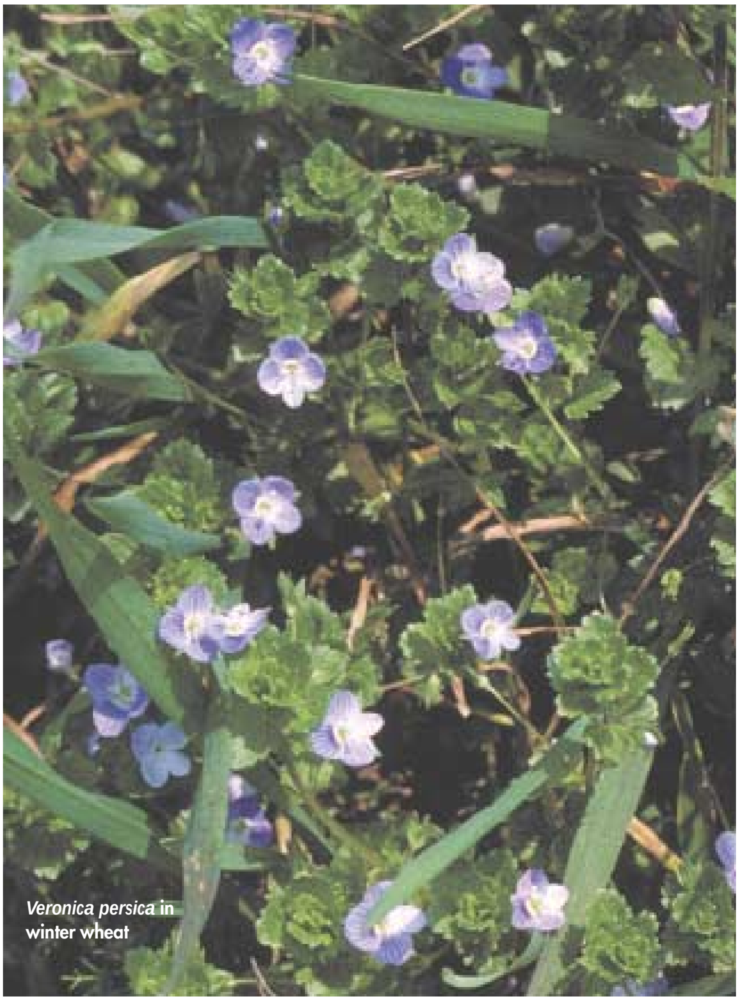
+ number of weed seedlings to cause a 5% yield loss
Figures in brackets – expert opinion/extrapolated values

Table 1. The competitive impact of a range of common weeds and their importance for invertebrates and birds

preserving rarer and beneficial indigenous plants of arable ecosystems. A further technological advance has been the development of spatially selective weed control that uses satellite-based global positioning systems (GPS). This enables herbicides to be applied to geo-referenced mapped areas of the field. In such systems, patches of weeds can be treated, leaving other areas of the field untreated. Decisions on which areas to treat can be based both on the impact of particular weeds on the crop and their population dynamics.

Weeds provide food for invertebrates and birds and are thus important contributors to functionally valuable biodiversity in arable ecosystems (Table 1). There have been declines in arable weeds and farmland bird species over the last 50 years, apparently associated with the intensification of agriculture. The causes of these declines are complex but there is a suggestion that maintenance of a diverse population of weed species is beneficial for arable field ecosystems. This ecological role conflicts with the traditional perception of weeds only as plants detrimental to yield. Consequently, there is a need to balance the control of aggressive competitive species and the retention of less damaging species that offer environmental benefits. This dual view of weeds poses a challenge for their management and emphasises the need for a sound understanding of population dynamics.

Recent research has enabled us to improve our knowledge and models of weed population dynamics allowing more precise prediction of population change and a better understanding of the degree and causes of variability. Some of this work is of direct application while other components are exploring more fundamental aspects such as matrix modelling techniques and the physiological basis for the different behaviour of weed species. It is not possible to study every one of the 200 or so plant species that can be classified as weeds, but it may be possible to group species into a restricted number of classes that define their phenology, growth and impact on the crop and the environment. Weed species deploy a limited number of strategies enabling them to thrive in the specialised environment of an arable field. Some of these strategies will be



Veronica persica in winter wheat

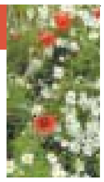
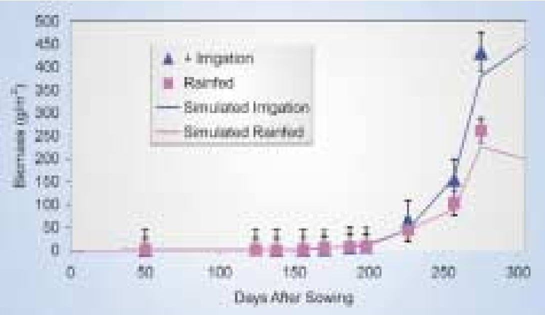


Figure 3. Actual and modelled response of *G. aparine* (measured as plant biomass) in winter wheat under high or low moisture conditions



antagonistic to the crop and seriously reduce yield. However, it is possible that a class of weed species can be identified which has a growth and reproduction strategy that is complementary to the requirements of the crop both spatially and temporally. Improved predictions of weed impact will help us to quantify the effects of changes in cultural practices on species that need to be effectively controlled, as well as those that offer environmental benefits and need to be retained.

Dealing with variability

One area of our work has focussed on identifying key environmental variables that cause variability in plant growth and fecundity in arable habitats. This work has made use of mechanistic simulation models of plant growth in mixtures together with an extensive array of basic physiological parameters.

The work has quantified the impact of environmental stochasticity on the growth and reproduction of some key weed species within a single year. Having quantified the likelihood of different levels of fecundity for weeds, the information can be incorporated into a stochastic version of our weed population dynamics model.

Soil moisture is a key cause of variability in weed species like *G. aparine* (cleavers) and our work has revealed the rooting and water-use characteristics of this species, enabling us to predict the impact of variable soil moisture. The success of a mechanistic simulation model at describing the contrasting growth of a population of cleavers under rainfed compared to irrigated conditions is shown in Figure 3.

Weed management decisions – the role of population dynamics

The apparently conflicting dual role of weeds in arable fields makes decision making on weed management increasingly difficult. The development of a Decision Support System (DSS) for weed management in winter wheat (WMSS) in collaboration with ADAS, SRI and SAC, provides a mechanism to deliver solutions for the complex issues surrounding weed management. Such a system takes into consideration the impact of weeds on crop yield and offers optimum economic solutions. It also highlights the ecological value of the species and estimates the consequences of control techniques for both current and future crops, based on estimates of seed production and losses.

The real size of the threat from weeds lies in the large number of weed seeds in the soil that can germinate and infest current and future crops. Within the DSS, the numbers of weed seeds in the soil and the numbers of mature weed plants that grow to compete with the crop are calculated through the course of a six-year crop rotation. The rotation must include winter wheat in one of the first two years but can include other crops such as oilseed rape, potatoes and spring barley in other years.

The simulation is carried out iteratively by calculating how many seeds there will be in the soil at the start of the next production year, given the numbers in the soil at the start of the current production year. These calculations are based on the numbers of:

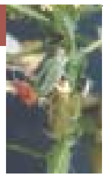
seeds that move from shallow to deep layers with cultivations;
seeds that produce seedlings;
seedlings killed by herbicides or hoeing;
plants that produce new seeds;
new seeds that are viable;
new seeds that are eaten by predators;
seeds that survive in the soil from one year to the next.

Given a specified sequence of crops, the DSS can calculate the most cost-effective combinations of weed control measures to ensure that the population of a particular weed is not allowed to increase to uncontrollable levels. Similarly, the husbandry that minimises the risk of extinction for rare or beneficial species can be identified.

This research is providing fresh insights into old problems and increasing our understanding of the role that weeds play in determining biodiversity in the farmland ecosystem. The programme ranges from fundamental studies of the role of weeds as crop competitors in a highly variable environment, and providers of food for invertebrates and birds, to developing systems to translate this information for the use of growers and advisors.

While insecticides retain an important role in crop protection strategies, the ability of insect and mite pests to evolve resistance to these chemicals remains a serious threat to agriculture in the UK and elsewhere in the world. Pest species with documented insecticide resistance in the UK (especially aphids, whiteflies and spider mites) attack a wide range of crops. Some can occur simultaneously on different crop species, making the development and coordination of insecticide use strategies problematical.

ROTHAMSTED RESEARCH



Insecticide resistance in aphids

Ian Denholm, Stephen Foster, Graham Moores, James Anstead and Martin Williamson

Potato aphid *Macrosiphum euphorbiae* – a potential new resistance problem. (left)

Rothamsted Research has a long history of investigating insecticide resistance from a number of perspectives ranging from biochemical and molecular analyses of resistance mechanisms to the evaluation of tactics for combating resistance under field conditions. Our work on aphid pests, especially the peach-potato aphid, demonstrates how a multi-disciplinary approach can facilitate resistance management through the development and continual refinement of mechanism-specific diagnostics, and an understanding of factors causing resistance to increase or decrease in frequency in field populations.

Diagnosis of multiple resistance in *Myzus persicae*

Challenges presented by resistance in aphids on arable crops are exemplified by the occurrence of multiple resistance mechanisms in the peach-potato aphid, *Myzus persicae*. This species attacks and can transmit virus diseases to several crops including brassicas, potatoes, sugar beet and lettuce.

M. persicae possesses three distinct mechanisms that collectively confer strong resistance to organophosphate, carbamate and pyrethroid insecticides. The first, discovered at Rothamsted 30 years ago, is based on the overproduction of one of two closely related carboxylesterase enzymes (E4 and FE4) that inactivate organophosphates, and to a lesser extent carbamates and pyrethroids before they reach their target sites in the insect's nervous system. Depending on the amount of carboxylesterase present, individuals of *M. persicae* are broadly classified into one of four categories: S- susceptible; R_1 – moderately resistant; R_2 – highly resistant or R_3 – extremely resistant.

The second mechanism, termed MACE (Modified AcetylCholinEsterase) is due to a modification to the insecticide target enzyme, acetylcholinesterase (AChE), which renders it insensitive to attack by the dimethyl carbamates, pirimicarb and triazamate. MACE resistance was first recorded in the UK

Damage caused by aphids feeding on potatoes in 1995 in aphids caught in Rothamsted's suction trap network. It caused severe pest control failures in eastern England in 1996 and has been present at varying frequencies thereafter.

In the last few years, we have identified a third resistance mechanism termed knockdown resistance or kdr, which is associated specifically with resistance to pyrethroids. Kdr involves a modification to the voltage-gated sodium channel protein in nerve membranes, which is vital for the normal transmission of nerve impulses and is the primary target site of pyrethroid insecticides.

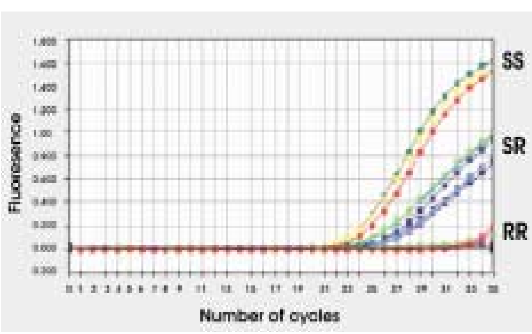
These three mechanisms: overproduced carboxylesterase, MACE and kdr, can be present in different combinations that have different implications for which insecticides are likely to be effective. An ability to diagnose these mechanisms individually and rapidly, ideally in single aphids, is therefore invaluable for anticipating and combating resistance problems. Biochemical assays for diagnosing overproduced carboxylesterase and MACE in single aphids have been developed at Rothamsted and are now used widely in many countries with resistance monitoring programmes for *M. persicae*. Kdr has proved more challenging in this respect since it is not readily accessible to biochemical tests based on electrophoresis, immunodiagnosis or kinetic measurements of target site inhibition.

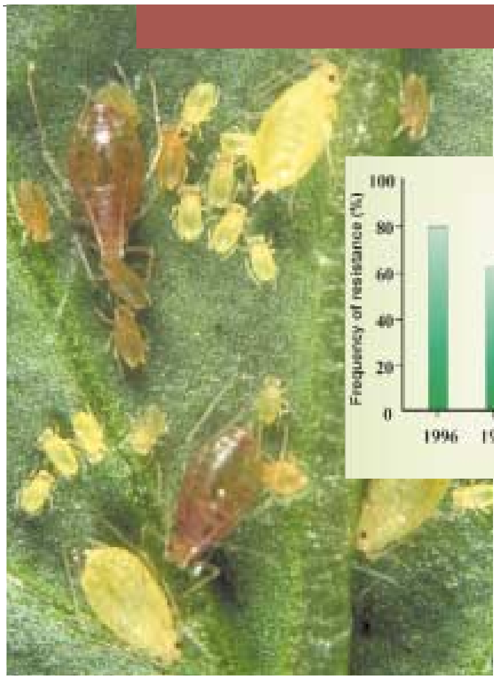
In vitro assays for kdr (as opposed to whole-organism bioassays, which are time-consuming and not mechanism-specific) have therefore relied on a knowledge of mutations leading to resistance in the sodium channel gene. Two such mutations have been identified within the domain II region of the channel protein: L1014F (leucine to phenylalanine) conferring 'basal' resistance to pyrethroids, and M918T (methionine to threonine) that appears to boost levels of resistance conferred by L1014F alone, leading to virtual immunity to pyrethroids applied at manufacturer's recommended rates. Several sequence-based approaches have been attempted, the most successful being the recent development of allelic discrimination PCR assays specific to each of the two mutations using fluorescent Taqman® MGB probes (Figure 1). These assays are designed to run alongside existing ones for overproduced carboxylesterase and MACE, and this suite of tools collectively enables a single aphid to be assigned to one of 108 possible genotypes encompassing all three resistance mechanisms. To our knowledge, this level of precision is unprecedented for any multi-resistant insect pest.

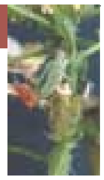
Dynamics of resistance mechanisms

The availability of this gamut of diagnostics has enabled us to track changes in the frequency of resistance mechanisms, relating these to the control measures adopted and the biological characteristics of *M. persicae*. Aphids for these surveys have come directly from field crops and from 12.2m suction traps deployed around the UK as part of the Rothamsted Insect Survey. Two distinct patterns have emerged from this research. The first is a long-term periodicity with resistance being most frequent in years such as 1996 with severe aphid outbreaks (and hence greatest insecticide use) followed by declines in frequency over years when aphids are less abundant (Figure 2). Secondly, resistance frequencies usually show a characteristic increase within seasons as insecticides are applied, but then decline markedly before the start of the following cropping season. This shorter-term periodicity, like patterns observed over a longer period, demonstrates that resistance levels can, under certain conditions, decrease as well as increase and prevent an overall, sustained increase in the severity of resistance problems. Declines can be due to a number of factors but appear attributable in part to side-effects that resistance mechanisms impose on aphid biology, which may adversely affect their survival and/or reproduction in the absence of exposure to insecticides. Detailed studies at Rothamsted have shown that resistant individuals of *M. persicae* overwinter less successfully than their susceptible counterparts, that they are less fecund, and less responsive to external stimuli including the aphid alarm pheromone (E)-β-farnasene (Figure 3). This compound is released from cornicle secretions exuded by aphids when they are physically disturbed, for example by foraging predators and parasitoids. Neighbouring aphids respond to the pheromone by withdrawing their stylets from the plant and dispersing away from the pheromone source. The intriguing possibility that decreased responsiveness to (E)-β-farnasene could render resistant aphids more vulnerable than susceptible ones to parasitism or predation is currently being investigated.

Figure 1. Amplification plot of the sodium channel gene in *M. persicae* using a probe specific for the wildtype (susceptible) kdr allele labelled with 6-FAM ™. SS: homozygous susceptible at L1014F site, SR: heterozygous at L1014F site, RR: homozygous resistant at L1014F site.







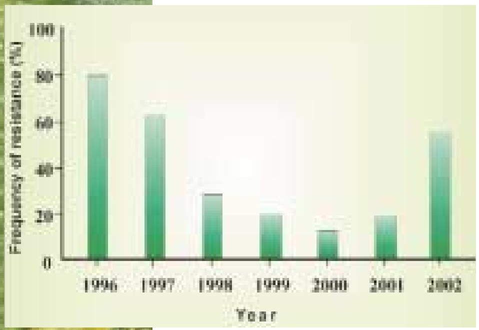


Figure 2. Frequency of the overproduced carboxylesterase mechanism (R_2 and R_3 levels combined) in aphid samples from field crops between 1996 and 2002.

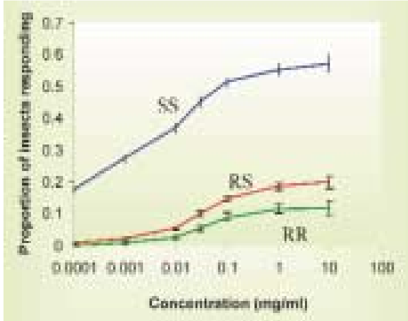


Figure 3. Response of aphids with and without the L1014F pyrethroid-resistance mutation to differing concentrations of alarm pheromone. SS = homozygous susceptible; RR = homozygous resistant; RS = heterozygote.

Emerging and potential new problems

For multi-resistant pests such as *M. persicae*, the introduction of newer insecticides can provide a valuable respite for growers, and an opportunity for researchers to integrate these into more sustainable management recommendations. Neonicotinoids (with imidacloprid as the commercial forerunner) and pymetrozine represent more novel insecticide groups available for use on some crops attacked by *M. persicae*, and which are unaffected by resistance mechanisms already present. However, their unrestrained use can unquestionably lead to selection of additional mechanisms, compounding the resistance problem still further. We have already identified clones of *M. persicae* from southern Europe showing up to 18-fold resistance to imidacloprid, and individuals with lower tolerance have been isolated from UK samples over the last three years. The commercialisation of neonicotinoids on an increasing number of crops harbouring *M. persicae* must therefore represent a significant new resistance risk requiring extensive co-operation between scientists, grower groups and agrochemical producers to address effectively.

Similarly, it is important to remain vigilant for the appearance of resistance in pests that have not posed problems historically. At present, the potato aphid (*Macrosiphum euphorbiae*) and the currant-lettuce aphid (*Nasanovia ribisnigri*) are both showing incipient resistance and are under investigation at Rothamsted.

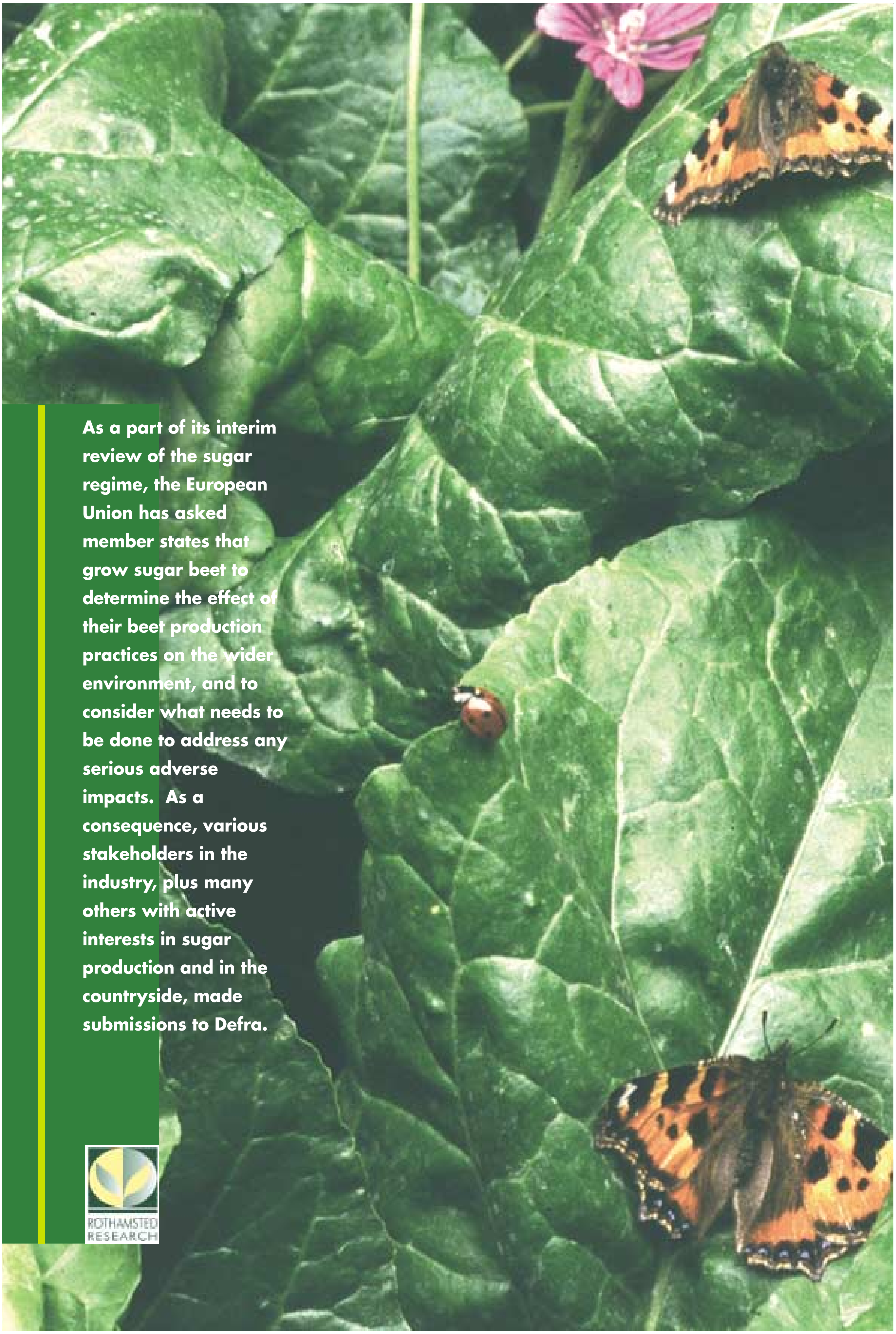
Exploitation

Continuing access to new tools in molecular biology offers greater insights into the processes governing the origin and spread of resistance, especially by combining markers for selected traits like resistance with ones (e.g. microsatellites) with no obvious adaptive significance. The reasons why some aphids such as *M. persicae* evolve resistance so rapidly whilst others (e.g. cereal aphids) do not, despite receiving insecticide treatments, should therefore become more tractable and provide greater scientific support for resistance management strategies, and risk assessment schemes built into pesticide approval procedures. Since the same resistance mechanisms often evolve in parallel in different species, diagnostic techniques developed for *M. persicae* may be transferred across species. For example, an elevated esterase implicated in resistance in *Macrosiphum euphorbiae* has been found to cross-react with antiserum raised for immunodiagnosis of overproduced carboxylesterase in *M. persicae*.

The insecticide resistance group at Rothamsted has a long history of collaboration with grower organisations, policy-makers, regulatory agencies and agrochemical companies, thereby ensuring effective extension of information and recommendations to end-users. In recent years, this has been formalised through the formation of the UK Insecticide Resistance Action Group (IRAG), chaired from Rothamsted, which reviews resistance developments of national concern and produces management guidelines. Outputs from our work on *M. persicae* are incorporated into a document "Guidelines for preventing and managing insecticide resistance in the peach-potato aphid *Myzus persicae*", available on the IRAG website (see below). These and related publications remain under revision to contend with new cases of resistance or a broadening of existing resistance problems.

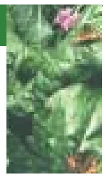
For further information contact ian.denholm@bbsrc.ac.uk or stephen.foster@bbsrc.ac.uk

The IRAG website is located at www.pesticides.gov.uk/committees/Resistance



As a part of its interim review of the sugar regime, the European Union has asked member states that grow sugar beet to determine the effect of their beet production practices on the wider environment, and to consider what needs to be done to address any serious adverse impacts. As a consequence, various stakeholders in the industry, plus many others with active interests in sugar production and in the countryside, made submissions to Defra.

ROTHAMSTED RESEARCH



The environmental impact of sugar beet production in England

Keith Jaggard

Food production now needs a "licence to operate", and in response to this the British Beet Research Organisation funded a two year research project to assess the impact of sugar beet production practices in England on the natural environment. This project has involved collaboration between Broom's Barn and the Agriculture and Environment Research Unit at the University of Hertfordshire.

We started by describing thirteen distinct production protocols, which encompassed the major differences in practice for beet growing in England; these were based on data from the annual British Sugar crop survey. The production protocols varied according to soil texture, organic manure and irrigation use, wind erosion control practices, weed and pest control regimes and organic production. No protocol included practices which are not recommended or which contravene the pesticide and nitrate vulnerable zone regulations; the sugar company has a pesticide audit in place to ensure that these contraventions are minimized and that beet is not delivered in the event of serious accidental breaches.

We then assessed the impact of each of these production protocols in Suffolk, Lincolnshire and Shropshire, to represent the weather in the areas of the country where beet is grown, and the underlying geology. Many impacts of beet production practices depend upon the type of habitat surrounding fields. No previous large-scale survey has classified the boundary habitats for arable fields in England. In order to supply this data we visually assessed video images of two opposite boundaries on about 600 sugar beet fields. The video film was created in July 2001 during a nine hour aerial survey along transects chosen to represent the whole UK beet crop. The survey was flown at an altitude of about 200m, so boundary features were clearly visible. Analysis showed that about 65% of beet crop boundaries are hedges, about 9% are

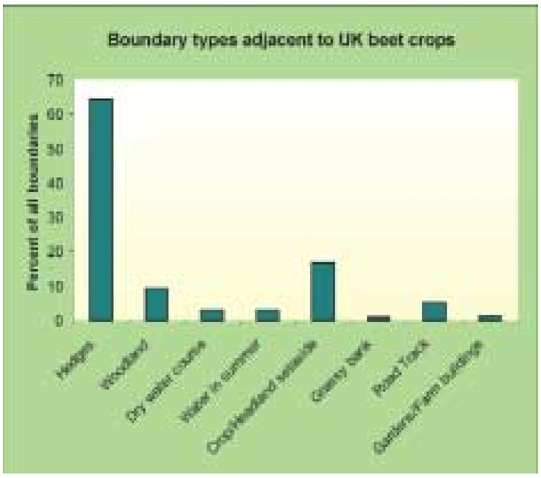


Figure 1. Types of vegetation in the boundaries of beet crops in the UK

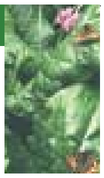
Variable growth in a beet field

Beet field with a cereal crop sown on the periphery

woodland or shelter belts and 17% are another crop or setaside, without any intervening natural vegetation (Figure 1). On average about 3% of the boundaries were ponds, streams or ditches which contained water at the time of the survey, but this differed significantly from region to region; from 7% in the Fens down to 1% in the remainder of eastern England.

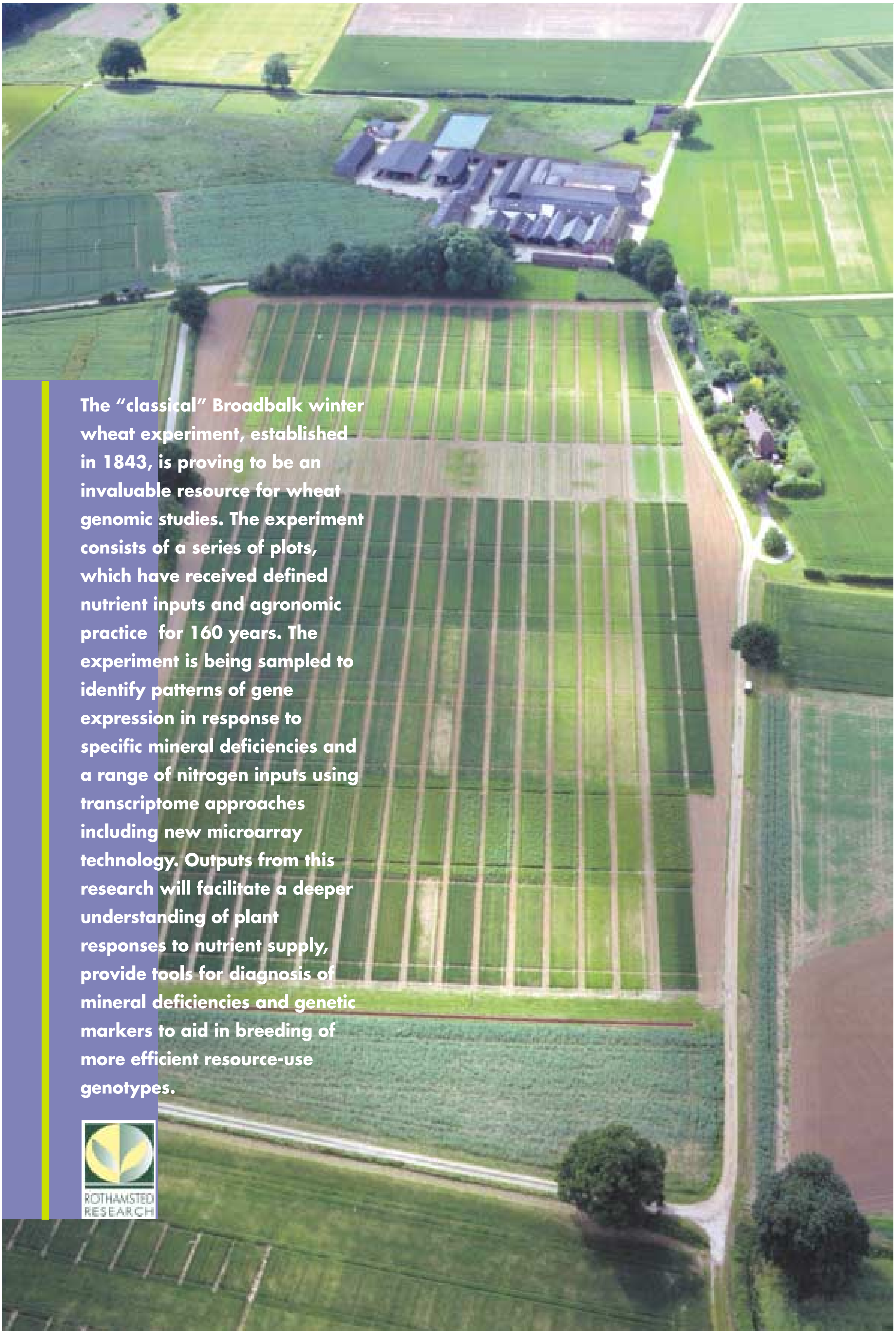
The pesticide risk assessment software, p-EMA, identified no serious risks associated with beet production. However, there were several minor risks to indicator species, mostly with the persistent insecticides aldicarb and imidacloprid. Aldicarb has now been withdrawn and imidacloprid is applied as a seed treatment so that the exposure of non target species is minimal. Where surface water was present the most frequent risks were associated with herbicides, especially on the silty and peaty soils where the most sprays have to be applied to achieve effective weed control. There were no significant risks that agrochemicals would pollute ground water.

The fate of nitrogen was examined by simulating denitrification, volatalization, leaching and crop uptake using the Rothamsted SUNDIAL model, for a crop sequence of winter wheat, sugar beet and spring barley;



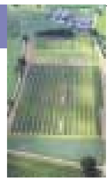
approximately 90% of all sugar beet follows a winter cereal crop. These simulations were made for all the soil textures on which beet is commonly grown, and for sequences of wet and dry seasons. Loss of nitrate during and after the growth of the beet was always negligible (less than 5kg ha^{-1}), but there were significant losses of N (up to 70kg ha^{-1}) by denitrification where organic manures were applied. If they can be devised, simple changes to farm practice to reduce these losses would be worthwhile.

The study also considered the energy input for all the production protocols. Consideration was given to raw material manufacture and transport, machinery manufacture, maintenance and fuel consumption, and to transport of beet to the processor. The total energy inputs ranged from 15 to 26 GJ/ha, and in common with other studies, those protocols which used little mineral N fertilizer consumed the least energy. The weighted average yield assumed for the production protocols was 52 adjusted tonnes/ha, and the energy yield, based on 16.9GJ t^{-1} of beet dry matter, averaged 202 GJ ha^{-1}, giving energy ratios which ranged between 8 and 13.5. These ratios are approximately double those that have been calculated for cereal production in NW Europe, and should make sugar beet a good candidate source for environmentally sustainable bioethanol production. A bonus would be the fact that beet is a spring sown crop (spring cropping provides a valued habitat for many species). The submissions to the EU on beet and the environment found that this was an important aspect now that 78% of all arable crops in eastern England are autumn sown.



The "classical" Broadbalk winter wheat experiment, established in 1843, is proving to be an invaluable resource for wheat genomic studies. The experiment consists of a series of plots, which have received defined nutrient inputs and agronomic practice for 160 years. The experiment is being sampled to identify patterns of gene expression in response to specific mineral deficiencies and a range of nitrogen inputs using transcriptome approaches including new microarray technology. Outputs from this research will facilitate a deeper understanding of plant responses to nutrient supply, provide tools for diagnosis of mineral deficiencies and genetic markers to aid in breeding of more efficient resource-use genotypes.

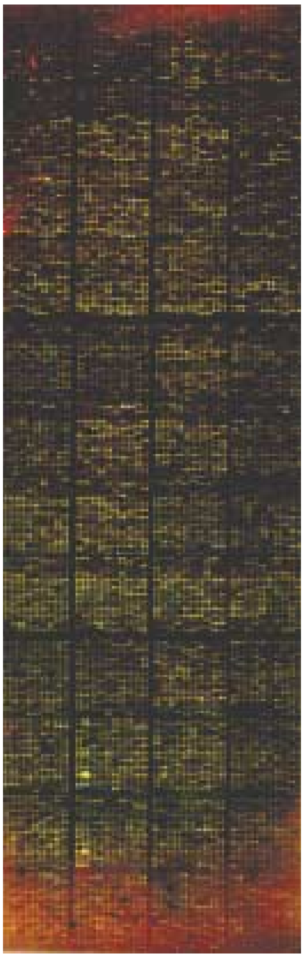
ROTHAMSTED RESEARCH



Genomics and the Rothamsted Classical Experiments

Malcolm J Hawkesford, Peter Barraclough, Jonathan R Howarth, Chungui Lu and Keith Edwards

Aerial view of The Broadbalk Classical Experiment. (left)



Background

The Rothamsted Classical Experiments were established in the 19th century by Sir John Lawes and Sir Henry Gilbert to investigate crop production and the influence of various combinations of inorganic and organic fertilisers on crop yields. One objective was to determine if the new inorganic fertilizers were as effective as farmyard manure in elevating crop yield. In addition, plots were established to express specific mineral deficiencies and these have been maintained with only minor modification ever since. The Broadbalk experiment represents a single field in which experimental plots have become established with distinct properties in relation to mineral availability and soil quality. It is possible to sample a wide range of treatments at this single site. Grain yields for the various plots have been recorded continuously and sample information is shown in Table 1. A clear response to applied nitrogen is evident with traditional farmyard manure comparing favorably to inorganic N applications. The specific mineral deficiencies have substantial influences on. Since 2000, one plot has received no sulphur (S) fertilizers. In 2002 yields on this plot were reduced for the first time by c 1 t ha^{-1} compared to the controls.

In 2002, the first extensive samplings for molecular analyses were undertaken. Tissue samples were harvested both during the vegetative growth phase and at defined time points during early grain development. Messenger RNA (mRNA) was extracted from these tissues and is being subjected to transcriptome analyses using microarray and cDNA AFLP (amplified fragment length polymorphism) techniques.

Microarrays for whole transcriptome analysis

The BBSRC Investigating Gene Function (IGF) initiative has sponsored the development of a 10,000 unigene microarray chip. This has been produced in a collaboration between Rothamsted Research and Professor Keith Edwards (University of Bristol). The 10,000 genes represent a substantial proportion of the whole wheat genome and are drawn from a range of cDNA libraries from different tissues, grown under a variety of conditions. A collaborative project is underway between Rothamsted Research and the University of Bristol to

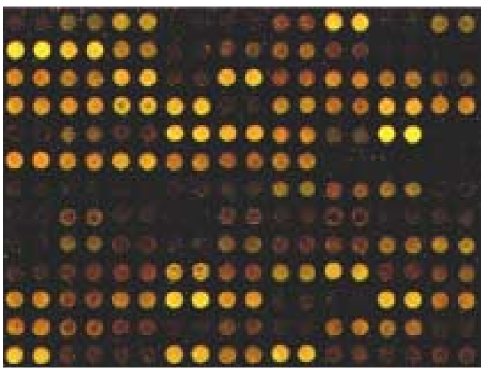


Figure 1. Hybridization of 10,000 duplicated cDNAs on a single glass slide and close-up

analyze gene expression in wheat grain in relation to nitrogen inputs using material sampled from Broadbalk. Figure 1 shows an example microarray, with the 10,000 genes (amine-modified DNA) spotted in duplicate. This array has been hybridized with cDNAs made from two mRNA populations from wheat grain supplied with high and low rates of N. The cDNA populations are labeled with either a red or green fluorescent dye. The fluorescence intensity is directly related to the level of gene expression and the relative fluorescence of the two dyes, which may be accurately and independently quantified, compares the effect of the treatment on expression for each individual spot or clone. The fluorescence intensities for each spot may be plotted graphically (Figure 2). Most genes are expressed at similar levels and are plotted within the green delimiting lines, which represent experimental error. Points above the upper line or below the lower line represent preferential expression in the high and low nitrogen treatments, respectively. Each of these points represents one gene of the unigene set, whose sequence is known, and in many cases, whose identity has also been ascertained. The differentially expressed genes may be clustered into functional groups, and responses of whole biochemical pathways, at the level of gene expression, may be monitored in a single experiment. The output from this project is providing insights into the coordination of gene expression and biochemical pathways during grain development in response to nitrogen nutrition.

Screening for nutrient-regulated genes

Genes responding to specific nutrient deficiencies are also being identified. The approach is to sample leaf tissues from the nutrient deficient plots on Broadbalk at a time of rapid vegetative growth and high nutrient demand. The mRNA is extracted and a cDNA AFLP analysis is conducted. In this approach sets of oligonucleotide primers are used to generate cDNA fragments representing every gene expressed under each treatment. These fragments are then separated by gel electrophoresis allowing gene expression profiles to be compared (Figure 3). Using appropriate primer combinations, several thousand fragments can be resolved. An advantage of this approach is that gene analysis is not restricted to clones represented on the microarrays, where stress-induced genes may be under-represented. The differentially expressed fragments are excised directly from the gels, amplified, cloned and sequenced. The identity of the cDNA is determined by interrogation of gene sequence databases and the corresponding gene may then be isolated from a genomic library. Particular emphasis is placed on the isolation of the genomic region adjacent to the coding sequence as this contains the relevant control regions. Fusion of these control regions (the promoter) with a reporter gene allows the easy monitoring of expression when this construct is re-introduced into a plant. Methods for both transient and stable expression are being used to characterize the control regions. To date a number of candidate genes whose expression is controlled by specific nutrient limitations have been identified.

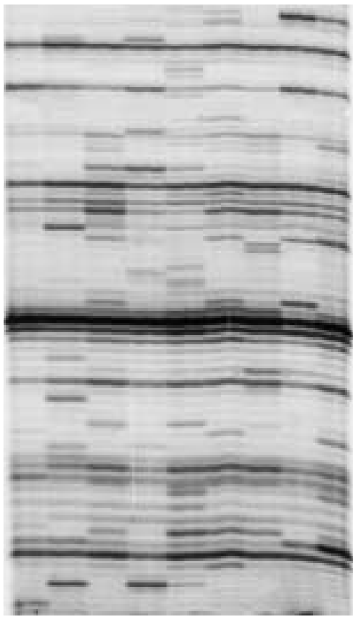


Figure 3. Section of a cDNA AFLP gel showing transcripts from nutrient deficient plants grown on Broadbalk

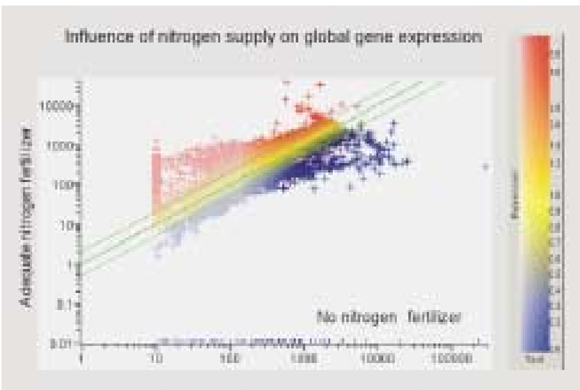


Figure 2. Scatter graph for visualization of relative expression between two treatments (high and low nitrogen-supply on Broadbalk) from a microarray experiment

Table 1. Grain yields of winter wheat (cv. Hereward) from a Broadbalk section of plots which have had wheat grown continuously (Section 1). Treatments are: farmyard manure (FYM), various levels of N in multiples of 48 kg/ha (N0 to N6) and K, Mg and P-deficient plots.

Treatment	Mean grain yield (1996-2000) ± std dev. (t/ha @ 85% dry matter)
FYM + N2	8.20 ± 0.50
FYM	5.99 ± 1.03
N0	1.28 ± 0.35
N1	3.18 ± 0.28
N2	5.28 ± 0.69
N3	6.10 ± 1.09
N4 (control)	7.16 ± 0.53
N5	7.62 ± 0.88
N6	8.00 ± 0.62
K-deficient (+N4)	3.61 ± 0.77
Mg-deficient (+N4)	4.77 ± 0.61
P-deficient (+N4)	1.91 ± 0.41

Exploitation

Differential gene expression, which correlates with nutrient use efficiency, may be directly responsible for the variation in this important trait, or may be a consequence of nutrient availability. If a direct causal relationship can be demonstrated then allelic variation of specific genes may become targets for selection in plant breeding programmes or for modification by genetic engineering to achieve improved nutrient use efficiency. Alternatively, if consequentially related, such genes may also provide useful indicative markers for breeding programmes or in the case of nutrient-deficiency induced changes in gene expression useful diagnostic markers. Laboratory-based analysis of marker-gene expression using, for example, PCR techniques, could be routinely supplied to the agricultural community (see Figure 4). However, it is highly desirable to achieve real-time analysis in the field, such that nutrient requirements of a standing crop may be directly fulfilled by appropriately precise fertilizer application. To supply this need, the concept of 'smart plants' has been proposed. The smart plants, which are transgenic lines containing the nutrient regulated promoter coupled to the reporter gene, would signal incipient deficiency in a sensitive and specific manner. The ideal reporter gene would give an easily measurable visible signal dependent upon nutritional status. Suitable sensors, perhaps located on the tractor supplying the fertilizer would respond to signals from either the crop plant or reporter plants scattered throughout the field ('sentinel plants'). This would enable the precise delivery of fertilizer.

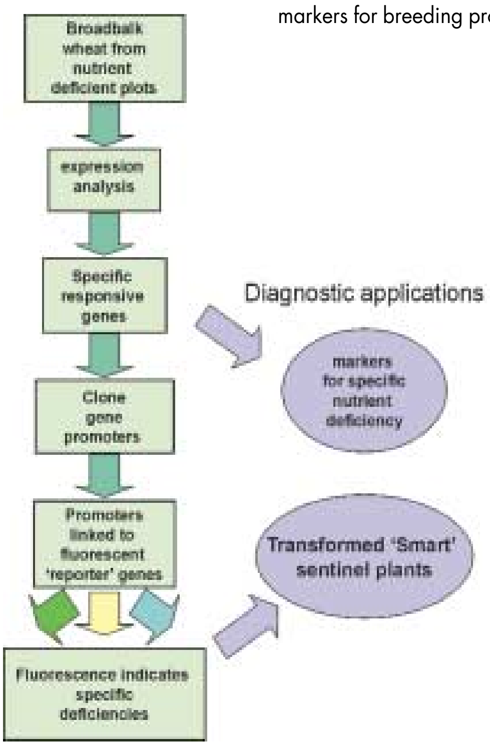
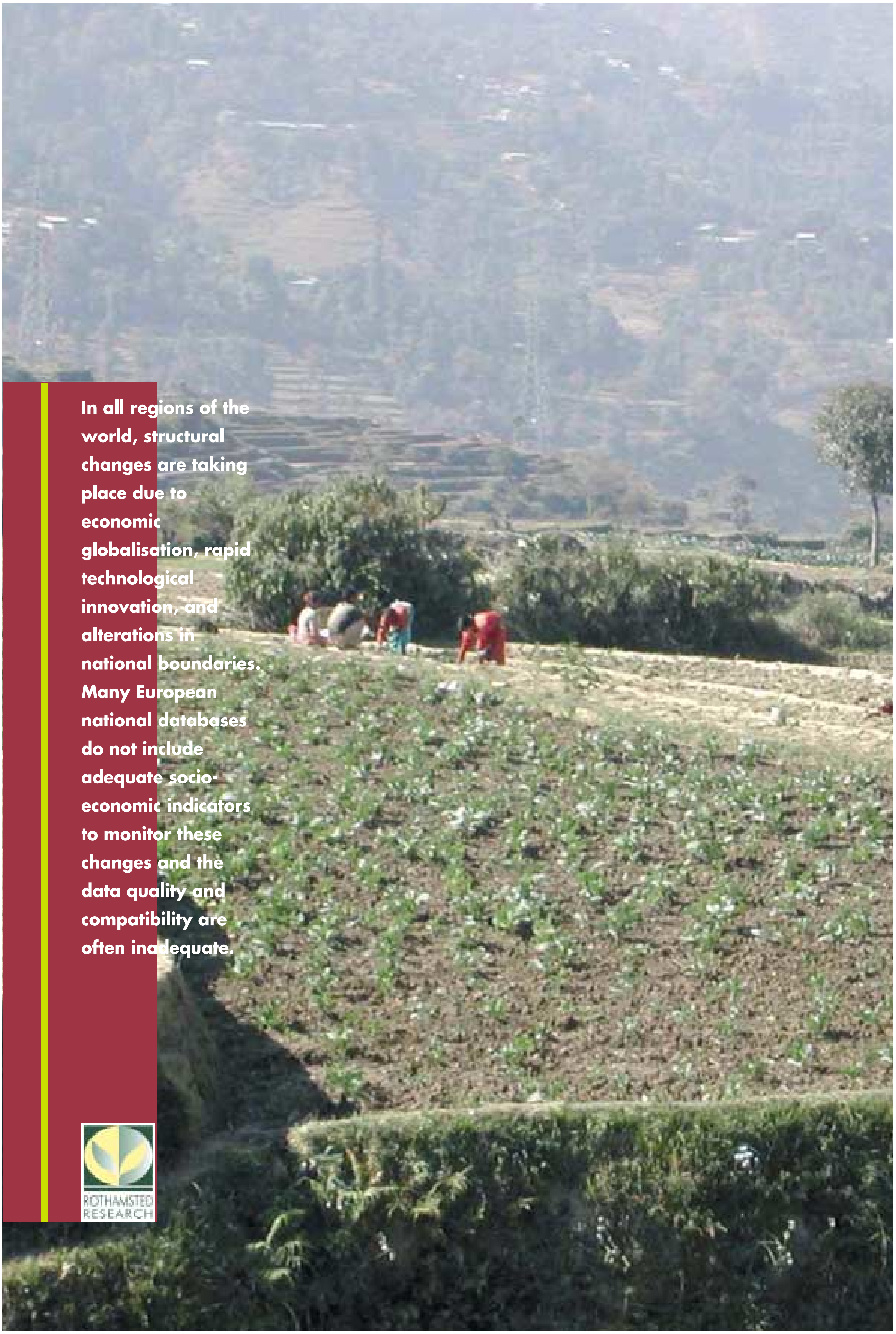
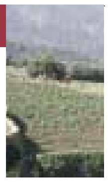


Figure 4. Development of diagnostic applications from expression profiling experiments



In all regions of the world, structural changes are taking place due to economic globalisation, rapid technological innovation, and alterations in national boundaries. Many European national databases do not include adequate socio-economic indicators to monitor these changes and the data quality and compatibility are often inadequate.

ROTHAMSTED RESEARCH



Interactions between the environment, society and technology

Janet Riley

Women working on terraces in Nepal. (left)

Describing a participatory method. (right)

Introduction

Dialogue between different groups in society is becoming ever more important in a world that is increasingly interlinked. Such communication must take into account structural aspects and diversities such as socio-economic status, cultural values, gender, employment availability, poverty levels and age. These complex inter-relationships need to be translated into a language understood by both political decision-makers and the players of civil society.

This is a new area of work that the Institute is seeking to make a contribution to, primarily though funding from DFID (Department for International Development) and the European Commission. It is very different to the traditional science carried out by Rothamsted, but at a national and international level, such cross-cutting work is seen as vital. Rothamsted, with its history of research in sustainable agriculture is well-placed to make such a contribution.

INTEREST

The UNIQUAIMS (Unification of Indicator Quality for Assessment of Impact of Multidisciplinary Systems) project, funded by the European Commission and co-ordinated by Rothamsted Research from 1998-2002, highlighted the poor appreciation of knowledge structures and relationships, as well as the inadequacies of indicators by which social and economic change are assessed. The collection of socio-economic data is scarce and irregular while reliable indicators of both environmental change and sustainability are poorly developed.

The on-going INTEREST project (Interactions between the Environment Society and Technology), also funded by the European Commission and co-ordinated by Rothamsted, is studying the current farmer and community ecosystem practices in five ecosystems in India, Sri Lanka and Nepal. It will link this to available scientific knowledge to analyse and describe changes in the pressures between environmental policy, social challenges and technological innovation. By the end of the project a range of dissemination tools will have been developed to deliver this improved knowledge to all levels of society. This will provide a greater understanding of environmental challenges at all social levels and lead to improved ecosystem management strategies for sustainable livelihoods.

India, Haryana

Degraded forest bamboo ecosystems

There are 125 indigenous, as well as exotic species of bamboo belonging to

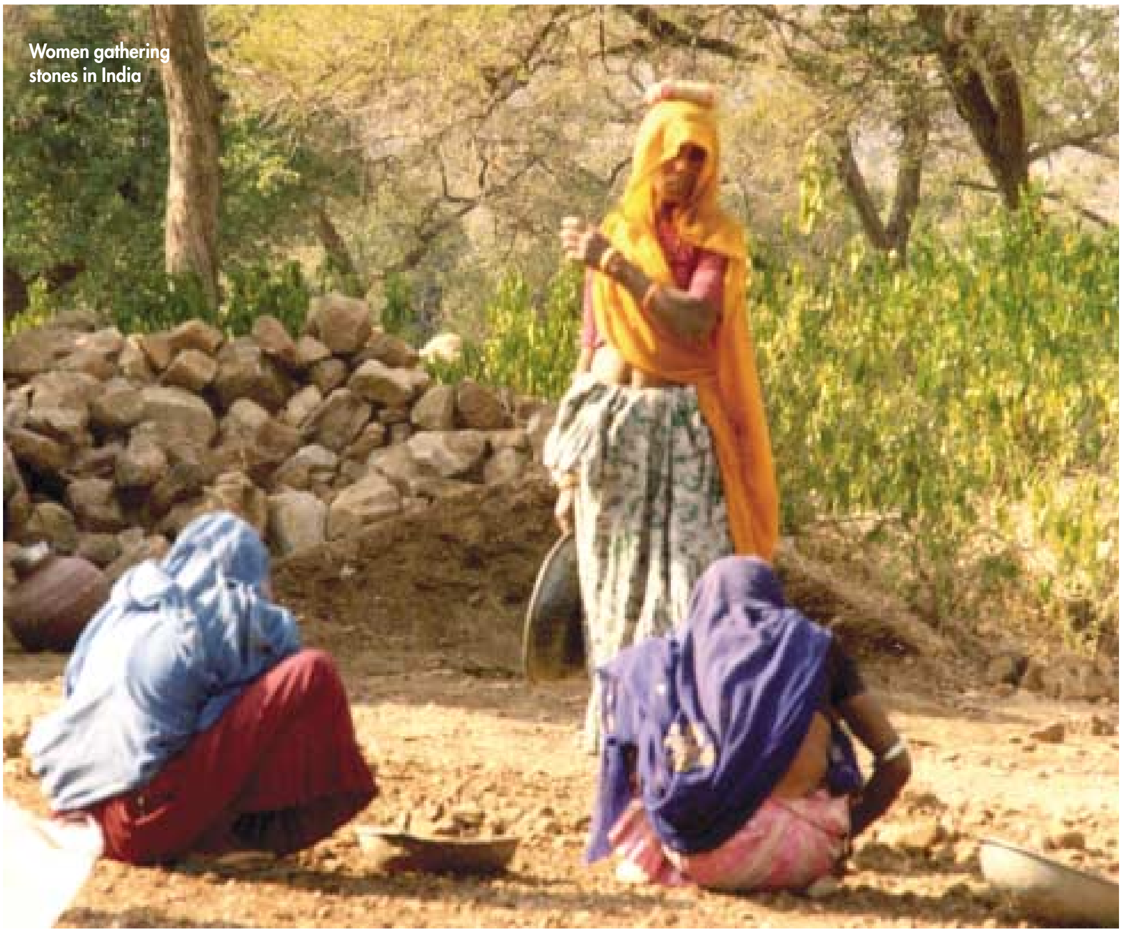
Conducting a participatory methods workshop in Sri Lanka

23 genera, occupying 10.03 million ha (12%) of the total forest area of India. Bamboo is used extensively in India to support livelihoods, for basket-making, medicines, charcoal (for batteries), paper pulp and fodder. The intricate rhizome systems of bamboo are also useful for soil conservation. The Bhanjdas, the basket-making community of Haryana, are solely dependent on bamboo. After the formation of the State of Haryana, the Haryana Forest Department issued permits for bamboo extraction to the Bhanjdas, but population pressure and the growth of the market economy resulted in degradation of the bamboo system. A formal liaison between local communities and the Haryana Forest Department has reversed the degradation and has provided employment, more bamboo and community funds. Some social, economic and legal hurdles still exist, such as poor returns on sales. The process of change and reasons for the existence of legal hurdles is the subject of this study.

India, Karnataka

Small-scale farming systems in the peri-urban and rural areas of Karnataka

Farms and systems in this region are small (less than 1 ha land) and the main crop in the coastal region is paddy grown in three seasons, *khariff*, *rabi* and summer. Further inland, cash crops such as arecanut, coconut, cocoa, pepper and cashewnut are grown. Pulses and commercial sugar cane are also cultivated. Over the last few years there have been changes



Women gathering stones in India

from non-commercial monsoon-dependant rice paddy to commercial irrigated crops of coconut, arecanut and sugarcane. This is partially due to rising labour costs, difficulties with paddy cultivation, environmental factors, such as increased soil salinity, and low returns on produce. The process of this technological change and its impact upon societies and the environment is not fully understood as it has not been monitored in depth.

India, Goa

Degraded aquaculture systems

The traditional khazans aquaculture systems are based on the principle of salinity regulation and tidal clocks. Estuaries, mangrove areas, embankments (*bunds)*, creeks, sluice gates and drainage canals are part of these complex systems which are being damaged by local people in pursuit of short term economic gain. The ecological balance of the system has been altered through the introduction of non-traditional species and fishing systems. Other problems include the salinisation of the land, caused by inadequate maintenance of embankments, availability of markets and changes in management arrangements. The processes underlying these technological changes must be understood and then the relationships between the impact of these changes upon societies and the environment can be determined.

Sri Lanka

Small-holder rubber production

Large and medium estates account for most of the rubber production in Sri Lanka. Rubber production on the 155,000 small-holdings of less than 4 ha each accounts for about 33% of the total rubber production. Poor performance of these small-holdings has been related to unsatisfactory diffusion and adoption of new technologies. The four most important management practices to ensure reduction in immature periods and promote high latex yields are the use of high yielding clones, application of recommended fertiliser levels, weed control and ground cover management. Understanding of the social, technological and economic reasons for non-adoption of these technologies and the interactions between them is necessary. Also of importance is the Sri Lankan government's formation of small-holder societies, *Thuru Saviya,* to help them in marketing, providing subsidised materials, low-interest loans for smoke house construction/renovation and improving technical know-how.

Nepal

Degraded forest-watershed systems

The typical Tamang village setting is of about 100 ha set in the mountains with forests, rivers, agricultural land (rainfed and irrigated), and grazing lands. The forests, (and associated rivers and land) formerly government-managed, are now run by the local communities. Women, particularly, use the natural resources in an integrated way to meet their basic needs, applying indigenous knowledge and making decisions by a democratic process. The type of livelihood is often caste-based with the Brahmin/Chhetri being most active in tree-growing. The resource base is facing great pressure to meet both basic needs and market demands.

Our partners, TERI (Tata Energy Research Intitute) of India, the Rubber Research Institute of Sri Lanka and ENPHO (Environment and Public Health Organisation) of Nepal, gathered local data in these ecosystems. The teams undertook RRA (Rapid Rural Appraisal) for each study area, field visits to collect and study data, open interviews with key participants along with a detailed household survey, and PRAs (Participatory Rural Appraisals).

The collected data have now been analysed by the Asian teams and the results presented at the first workshop, held in Nepal last December. Potentially useful indicators have been identified. Interventions are being applied during the second year to introduce changes to the systems and monitor these in

A sluice gate controlling a Khazans aquaculture system

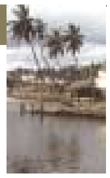
parallel with present systems. Future work will build on this with further data collection and analysis to refine the indicators. Finally we will have an appreciation of the key pressures and indicators causing change in the selected ecosystems and the changing relationships between the key technological, social and environmental pressures of each ecosystem.

A variety of ways will be developed to share this information with the public, from scientific reports and formats appropriate to funding bodies and governments, to locally distributed materials in local languages in each ecosystem.

In Sub-Saharan Africa agriculture provides about 70% of employment, 40% of exports and one third of GNP. Two-thirds of the region's 615 million people live on small farms with low-productivity (Conway and Toenniessen, 2003). The Sub-Saharan population is the world's largest remaining concentration of people who go to bed hungry, with about one third of the population routinely lacking sufficient food. The numbers of hungry people will increase as food production per capita declines as a consequence of rapid population growth and low crop yields. The latter result from depletion of soil nutrients and losses caused by pests, diseases and abiotic stresses (ibid). We describe some of the work in Rothamsted Research, aimed at contributing to the challenge of achieving food security in Sub-Saharan Africa.

ROTHAMSTED RESEARCH

Conway, G. and Toenniessen, G. (2003) Science: 299 1187-1188



Rothamsted Research in Africa – focus on phytoplasma diseases

Phil Jones

The African continent is characterised by its range of climate and ecosystems, including Mediterranean regions, dry sub Saharan scrub, tropical rainforests and savannah. The phytoplasmas are microscopic prokaryotic plant pathogens that can exploit crops in all these environments.

The most devastating phytoplasma diseases are observed in coconut growing regions. Cape St Paul Wilt disease destroys tens of thousands of coconut palms every year in Ghana. The same phytoplasma also causes Bronze Leaf Wilt or Awka disease in Nigeria. Rothamsted has been working with the Coconut Programme of the Council for Scientific and Industrial Research in their search for genetic resistance. In East Africa, Coconut Lethal Decline is caused by a phytoplasma with a slightly different genome to the Cape St Paul Wilt phytoplasma. This difference means that varieties of coconut resistant in West Africa are highly susceptible to the phytoplasma in east Africa. The use of molecular markers developed in Rothamsted Research should help speed up the selection of new coconut varieties for disease resistance.

Sugar Cane Yellow Leaf Disease results in a reduction of sugar content and an increase in other polysaccharides that can gum up processing plants. As sugarcane is largely a vegetatively propagated crop it is important that seed cane is not produced from plants infected by phytoplasmas. This disease was thought to be a nutritional disorder but Rothamsted investigations have shown that it is caused by at least two different phytoplasmas. Collaborating institutes include the South African Sugar Experiment Station and the Mauritius Sugar Industry Research Institute.

White Tip Die Back and Slow Decline are two lethal diseases of date palms in Sudan that Rothamsted studies, conducted in conjunction with FAO, have also associated with phytoplasmas. Ribosomal RNA sequence data have shown them to have a 99% similarity with the phytoplasma that causes White Leaf Disease of Bermuda grass, a common weed in date palm groves. As date palms are vegetatively propagated, growers must take care that only uninfected palms are selected for propagation.

In Kenya, Napier grass is grown extensively as a fodder crop and as a soil stabiliser. Recent work by Rothamsted Research and ICIPE has shown that this grass can also be used as a trap crop to control stem boring moth larvae. However, in the past year a serious yellowing and stunting disorder of Napier grass has spread through the Kitale region of Kenya. All eleven samples sent to Rothamsted tested positively for the presence of phytoplasma. Sequencing of the 16S

Phytoplasmas

The phytoplasmas are a group of prokaryotic, microscopic plant pathogens that cause over 700 diseases of food, fibre and ornamental plants. They are found mainly in the phloem sieve tubes of their plant hosts and in certain sucking insects, which can act as vectors. They can also be spread by grafting, by parasitic plants or by seed transmission. Detection of phytoplasmas is by grafting to susceptible host plants, microscopy, serology (ELISA), nucleic acid hybridisation or DNA amplification using the polymerase chain reaction (PCR). Symptoms displayed by plants infected with phytoplasmas include foliage yellowing, petal greening, shoot proliferation, stunting, little leaf formation, necrosis and a decline of vigour leading to death.

rDNA and comparison with other phytoplasma sequences has shown that the phytoplasma is related (86% similarity) to the Bermuda grass White Leaf phytoplasma. Work is continuing in conjunction with colleagues at KARI to ascertain whether spread is due to an insect vector or solely by vegetative propagation.

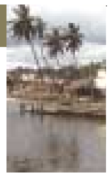
The phytoplasmas were once thought to be viruses but they are in fact members of the class Mollicutes, microscopic organisms that do not have a cell wall. Other members of the Mollicutes include spiroplasmas (helical motile organisms which infect plants and insects) and mycoplasmas (which infect animals). Phytoplasmas were originally classified according to their disease symptomatology but this has been replaced by phylogenetic analysis based on their 16S rDNA. Currently fourteen groups of phytoplasmas are recognised. Phytoplasma genomes range in size from c.500 to 1600Kb and several research groups world-wide are attempting to sequence complete genomes, a job made more difficult because these organisms cannot be grown in pure culture.

Rothamsted International in Africa

Stephen James

Rothamsted International (RI) Fellowships are entirely supported by the generosity of charitable donations from Rothamsted staff, Trusts and Foundations as well as companies, including the covenanted profit of Rothamsted International Consulting Limited.

The scheme gives excellent researchers from developing countries the chance to extend their scientific knowledge and skills by drawing on the facilities and resources at Rothamsted to address problems of their own country. In this way RI Fellows target the sorts of issues that are impeding the development of agriculture, assist in the development of research capacity where it is needed and so help in the fight to provide food security and alleviate poverty. Now celebrating its 10th anniversary, the RI



fellowship scheme has provided such opportunities for over 90 visiting Fellows, the vast majority of whom have returned home (a condition of the Scheme) to transfer technology through university teaching, extension services and commercial exploitation. A particularly important feature of the scheme is the extended period of preparation between the researcher in the host laboratory and the visitor. This allows both parties to get maximum benefit from the typical 12 month Fellowship period.

Rothamsted International team

Coming from Ghana, Kenya, Nigeria and South Africa, African RI Fellows have participated in a wide range of the Institute's work.

Integrated crop management relies on the understanding of how insecticides can have undesirable impact upon the natural enemies that act to limit pest numbers in natural situations. Insecticides can affect foraging and performance as well as having directly lethal effects. Understanding this can ensure that insecticides are only applied at optimum periods to minimise undesirable effects. Other studies have included those designed to enhance the reservoir populations of natural enemies by providing appropriate food (host) sources. This may require using a small area of land for this purpose and this is not an easy decision when land is limited and crop losses are high. Fellows have also been involved in understanding the chemical cues that determine behaviour of pests such as the Sorghum Midge (*Astylus atromaculatus*), a major problem on an important staple crop in Africa.

Statistical methods for analysing and describing the movement of pests in space and time have to be rigorous and robust. A Fellowship in this area was supported through donations made by staff at Rothamsted. In an article elsewhere in this Annual Report, Janet Riley describes how research in statistics has much to contribute to improved experimentation allowing the maximum amount of information to be extracted from carefully designed experiments.

A Fellow from Nigeria was able to undertake an extensive study of reports of herbicide resistance in grass weeds affecting cereal crops in her country. Careful work revealed that the problem was not in fact one of resistance, but poor responsiveness to the chemical was due to incorrect application both in timing and methodology. As a result the Fellowship was re-targeted to understanding pesticide use, so helping to avoid abuse of these, sometimes expensive, chemicals.

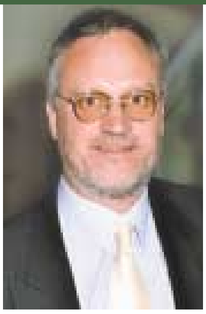
Over half of the sugar cane in South Africa is grown by small holders and one of our RI Fellowship projects was aimed at contributing to the global effort to control phytoplasma disease in this important crop.

Despite the success of the RI Fellowships, it is of concern that of our 90 Fellows, only eight have come from Africa. Rothamsted International wishes to increase the proportion of Fellows from this region of the world that particularly needs to harness agriculture as an engine for growth.

If you share this aim and could contribute to the support of Rothamsted International please make contact with the office. Similarly, get in touch if you are a researcher working in Africa and believe you or a colleague could benefit from the experience of 6-12 months at Rothamsted. http://www.rothamsted.bbsrc.ac.uk/ri/ri.htm

Sunday Ekesi inoculating aphids with a fungal pathogen

The Arable Research Institute Association (ARIA)



David Brightman

ARIA is the Members' Association of Rothamsted Research and was launched in 1990, merging the Long Ashton Members' Association and the Friends of Rothamsted. ARIA aims to forge two-way links between the Institute's scientists and people involved in the cereals and arable farming business. Members have privileged access to the latest developments in agricultural research through direct contact with scientists involved in relevant research programmes. Regular interactive workshops on targeted research topics are run throughout the year and members receive a quarterly newsletter covering different aspects of Institute science. The ARIA website is at http://www.rothra.org

ARIA is independent of Rothamsted Research and is run by a board of directors, chiefly appointed from the membership.

The past year has seen a great amount of change within the structure of ARIA, some of which is still ongoing. The secretariat move to Rothamsted was finally completed and at the AGM in November 2002, Dr Susannah Bolton took over the role of Company Secretary from Harry Anderson who retired after many years service to both the Institute and the Association.

This restructuring was carried out alongside the extensive changes within the Institute. ARIA must respond to new developments in the work of the Institute and in the needs of the industry. The face of modern agriculture has changed dramatically over recent times and the changes in ARIA are designed to reflect the needs of a wider membership, and to take account of new science that has been developed within the Institute. The first of these changes during the coming year will be to change the name from the Arable Research Institute Association to Rothamsted Research Association (RRA), thus reflecting the close alliance that the Association has with the Institute.

This however is all in the future and the past year has been successful in itself. The Science Day in June, entitled "Research and Development - Integrating Priorities and Fulfilling Industry Needs" was well attended and looked at addressing the issues that are becoming prominent in the arable sector. Senior figures from LEAF, HGCA, Defra and BBSRC, as well as speakers from various research organisations, all contributed to making it a success. A key output from the day was a report submitted to Defra by the Association, in response to the Defra

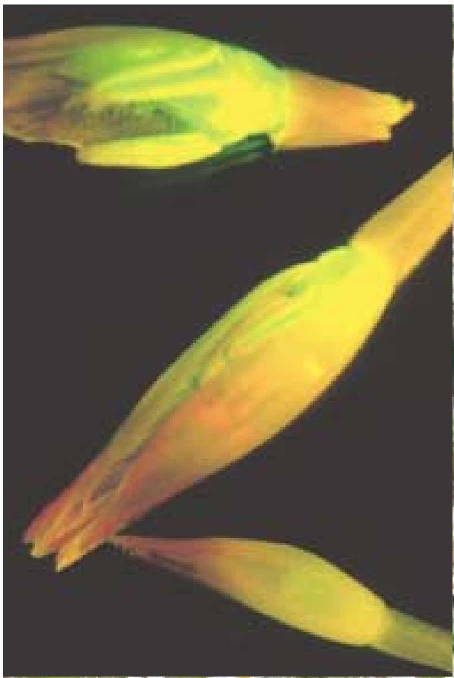
Stephen Moss contributed to the joint ARIA/HGCA workshop in January entitled "How to tackle herbicide resistance"

steering document, which followed the publication of the Curry report.

The AGM in November was held at Long Ashton and was a farewell from ARIA to the Station. The subsequent workshop focused on work that will be transferring from Long Ashton to Rothamsted, following the closure of the Long Ashton site. This covered a number of topics, including GM, understanding and improving the bread-making quality of wheat and genetic diversity. Harry Anderson also gave a presentation looking back at the 100 years of research that was carried out at the Long Ashton site.

January saw the first workshop run jointly with HGCA entitled "How to Tackle Herbicide Resistance" and held at Broom's Barn. It was a resounding success in terms of both presentations and attendance. This style of workshop, focusing on a specific subject and led by a scientist or expert in the field, has proved to be a popular format and will continue with further joint workshops planned. The first will be in April with a "Farm Strategies to Avoid Resistance" workshop, this time held at Newbury racecourse, and further events are planned for the coming Autumn / Winter.

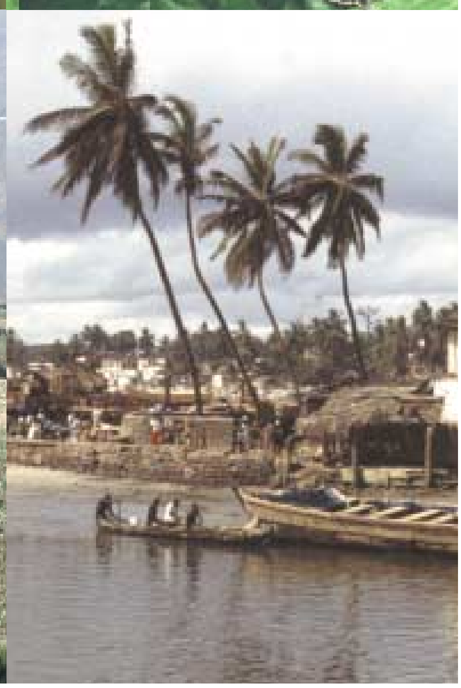
I would like to take this opportunity to thank all the staff of the Institute, both past and present, who have supported ARIA in so many ways. I am grateful to the board who have given both time and thought to the needs of the organisation and who have had the foresight to plan for change. Lastly I thank the members and others who have contributed to the events, which we hope have benefited both themselves and the Institute in promoting a modern industry based on sound science.











Research projects

Developmental Genetics
Holdsworth, M.J

Regulation and manipulation of gene expression during development and germination of cereal grains
Lenton, J.R
A transgenic approach to analyse susceptibility to pre-harvest sprouting and potential for improved resistance in wheat
Holdsworth, M.J
Analysis of cereal transplastomic technology for preventing the expression and spread of transgenes in pollen
Jones, H.D
Cereal community resources for investigating gene function
Holdsworth, M.J
Defining the genetic control of germination in Arabidopsis
Holdsworth, M.J
Development of the tools required to dissect large plant genomes and their application to a complex region of the maize genome linked to a disease resistant super locus
Holdsworth, M.J
Development of wheat allele (ASOS)
Holdsworth, M.J
Developmental cell biology of oilseed rape pods
Huttly, A.K
Do transgenes predictably alter the expression of the genome? Using wheat grain as a model
Holdsworth, M.J
Functional genomics of shoot meristem dormancy
Holdsworth, M.J
Molecular biology of embryo development and germination
Holdsworth, M.J
Monsanto Case Award
Jones, H.D
Regulatory gene initiative in Arabidopsis
Holdsworth, M.J
Structural and functional genomics for crop improvement
Holdsworth, M.J
The prevention of pod shatter in oilseed rape
Child, R.D
Tissue culture and transformation of diploid wheat species
Jones, H.D
To further develop, study, optimise and apply enabling cereal transformation technologies
Jones, H.D
Use of maize and rice Mar sequences to stabilise the expression of transgenes in wheat
Jones, H.D
ZEASTAR
Holdsworth, M.J

Signalling and Development
Hedden, P

Molecular cloning and characterisation of genes encoding cytochrome P450s of gibberellin biosynthesis
Hedden, P
Molecular cloning, function and structure of gibberellin-biosynthetic enzymes
Hedden, P
Molecular interactions between ethylene and gibberellin pathways in plants
Hedden, P
Putting insects off the scent; modifying plant semiochemistry to disrupt plant-insect interactions
Shewry, P.R
Regulation and genetic manipulation of gibberellin catabolism
Hedden, P
Regulation of gibberellin biosynthesis
Phillips, A.L
The physiological roles of gibberellin 20-oxidase isozymes in plant development
Hedden, P
The roles of gibberellin 3ß-hydroxylases in plant growth and development
Phillips, A.L

Stress Biology
Foyer, C

Detoxification of reactive oxygen species: Molecular strategies
Foyer, C
Increased nitrogen use efficiency in wheat: Towards a sustainable future (SUSTAIN)
Foyer, C
Integration of primary and intermediary metabolism for optimal resource use efficiency during stress
Foyer, C
Senescense and oxidative stress in plant systems
Foyer, C
The role of extracellular enzymes in xenobiotic metabolism and uptake in plants
Parry, M.A.J

Metabolic Signalling
Halford, N.G

Developing wheat genotypes with reduced nitrogen requirement by manipulation to decrease Rubisco content
Mitchell, R.A.C
Genetic regulation of sink strength in wheat and potato - GRiSSt
Halford, N.G
Improvement of Marama Bean an under-utilised grain and tuber producing legume for Southern Africa
Lawlor, D.W

MARISCO - Improving arable production systems by expressing marine algal rubisco in crop plants
Parry, M.A.J
Metabolic signalling and the partitioning of resources in plants
Halford, N.G
Molecular basis of changes in resource allocation induced by antisense SNRKI gene expression and environmental stress
Halford, N.G
OPTIMISE
Parry, M.A.J
Regulation and manipulation of Rubisco activity in crop plants
Parry, M.A.J
Source/ sink interactions and resource allocation: the role of carbohydrates
Paul, M.J

Metabolic Engineering
Beale, M.H

Cloning and characterisation of genes involved in xenobiotic metabolism
Theodoulou, F.L
Comparison of the metabolome and proteome of GM and non GM wheat
Beale, M.H
Diversification with crambe, an industrial oilseed crop
Glen, D.M
Engineering novel fatty acids desaturases
Napier, J.A
Expression patterns of gluten genes in transgenic wheat and their effect on grain processing properties
Jones, H.D
Fatty acid metabolism
Napier, J.A
Genetic enhancement of nutritional quality of grain sorghum
Shewry, P.R
Impact of water availability during development on the composition and functional properties of wheat
Shewry, P.R
Improved *Striga* control in maize
Beale, M.H
Isolation of DNAs for novel fatty acid desaturase enzymes and their use to manipulate fatty acid and triglycerol composition in transgenic plants
Napier, J.A
Managing late N applications to meet wheat protein market requirements using pre-harvest Near InfraRed (NIR) sensing
Shewry, P.R
Molecular biology of PUFAs
Napier, J.A
Molecular mechanisms of wheat protein elasticity
Halford, N.G / Shewry, P.R
Polyunsaturates fatty acid biosynthesis: Functional characterisation of novel elongase components
Napier, J.A
Structural and protein engineering studies of novel cereal and oilseed proteins with functional properties or biological activity
Shewry, P.R
The Arabidopsis functional genomics resource network: Metabolic profiling
Beale, M.H
The biochemical and molecular basis for grain texture in wheat
Shewry, P.R
The chemistry and molecular biology of plant signals hormones, defence and terpenoid secondary metabolites
Beale, M.H
The molecular basis for the emulsification properties of seed proteins
Shewry, P.R
Wheat gluten proteins: their characterisation and role in determining the functional properties and end use quality of wheat
Shewry, P.R
Wheat quality improvements through manipulation of storage proteins
Shewry, P.R

Nematode Interactions
Kerry, B.R

Biomanagement of root-knot nematodes in peri-urban agricultural systems
Kerry, B.R
Cultivar trial to assess reproductive rates and tolerance, Woburn 2002
Evans, K
Dupont Case award
Barker, A.D.P
Ecology of tritrophic nematode interactions (ECOTRAIN)
Davies, K.G
Impact of nematophagus fungi on potato cyst populations
Kerry, B.R
Integrated management strategies for potato cyst nematodes
Evans, K
Molecular genetics of interactions between plants and sedentary nematodes
Cabrera Y Poch, H.L
PCN Management Options - a desk study
Kerry, B.R
Potato cyst nematode control in Jersey
Kerry, B.R
Spatial distribution, dynamics and genetics of populations of potato cyst nematodes
Evans, K
Survey of South African soils for nematode destroying fungi
Kerry, B.R
The diversity of *Verticillium chlamydosporium* populations and its relevance to the regulation of nematode populations
Hirsch, P.R
The diversity, biology and dynamics of microbial agents that regulate nematode populations in the rhizosphere.
Hirsch, P.R / Kerry, B.R

Pathogen Population Biology & Disease Management
Lucas, J.A

Analysis of infection processes in plant pathogenic fungi
Lucas, J.A
Ascospores, fungicides and epidemiology of Septoria diseases on winter wheat
Fitt, B.D.L
Case Award - Douglas Arkell
Fitt, B.D.L
Characterisation and diagnosis of viruses affecting tropical crops
Jones, P
Development of an optical detection system for diseases in field crops (OPTIDIS)
McCartney, H.A
Development of field testing of fungicide anti-resistance strategies with particular reference to the strobilurin (QoI) group of fungicides
Lucas, J.A
Development of immuno-diagnostic techniques for light leaf spot (*Pyrenopeziza brassicae*) on winter oilseed rape
Fitt, B.D.L
Epidemiology of *Rhynchosporium* to improve barley risk assessment
Lucas, J.A
Epidemiology of winter oilseed rape diseases
Fitt, B.D.L
Evaluation of root diseases of winter oilseed rape in the UK
Evans, N
Evolutionary ecology of fungal plant pathogen divergence
Van Den Bosch, F
Fundamental studies of the interaction between environmental factors, crop pathogens and pests, and crops
McCartney, H.A
Identification of fungicide resistance markers in *Rhynchosporium secalis* and the effect of fungicides on populations of barley leaf blotch
Fraaije, B.A
INCO Fellowship - Dr Zbigniew Karolewski
Fitt, B.D.L
Indo - UK collaboration on oilseed crops
Nashaat, N.I
Indo - UK collaboration on oilseed crops (visiting scientists)
Nashaat, N.I
Interactions between cropping systems and soil-borne cereal pathogens
Jenkyn, J.F
Investigation into the epidemiology of Kalimantan wilt of coconuts in Indonesia
Jones, P
Optimising control of stem canker on WOR
Fitt, B.D.L
Pest and disease management system for supporting winter oilseed rape decisions (PASSWORD)
Fitt, B.D.L
Quantitative comparative plant disease epidemiology
Fitt, B.D.L
SECURE - Stem canker of oilseed rape: Molecular tools and mathematical modelling to deploy resistance
Evans, N
The role of volatile signals in plant-fungal interactions
Lucas, J.A
Understanding the evolution and dynamics of fungicide resistance development in cereal pathogens
Fraaije, B.A
Weather/disease interactions influencing winter wheat leaf disease epidemics
Van Den Bosch, F

Wheat Pathogenesis
Hammond-Kosack, K

A functional genomics approach to the identification of genes determining fungal pathogenesis of cereals
Hargreaves, J.A
Characterisation of plant virus transmission by fungi
Adams, M.J
Characterisation of resistance to the barley mosaic virus
Adams, M.J
Consortium for the functional genomics of microbial eukaryotes
Hargreaves, J.A
Effects of fungicides on take-all in wheat
Jenkyn, J.F
Epidemiology and control of fungally transmitted cereal viruses
Adams, M.J
Epidemiology of cereal stem base and ear blight pathogens
Bateman, G.L
Fungicides for controlling take-all in cereals
Bateman, G.L
Hazard analysis control of food contamination: Preventation of Fusarium mycotoxins entering the human and animal food chain
Bateman, G.L
Isolation and characterisation of pathogenicity genes
Bowyer, P
Maximising disease resistance escape and tolerance in wheat through genetic analysis and agronomy
Jordan, V.W.L / Lovell, D.J
Optimising the performance and benefits of take-all chemicals
Bateman, G.L
Pathogenicity of non-biotrophic fungi infecting cereals
Hammond-Kosack, K
Population biology and molecular ecology of plant pathogenic fungi
Bateman, G.L
Response of winter barley cultivars to barley mild mosaic and barley yellow mosaic virus
Adams, M.J
Strategies for the integrated control of take-all
Bateman, G.L

Plant Population Biology and Genetics

Karp, A

A weed management support system (WMSS) for weed control in winter wheat
Lutman, P.J.W
Bayesian inference of the genealogy of a predominantly selfing population from multi locus genotype data
Dawson, K.J
Determine effectiveness of AEF6102-04H alone and in tank mixture for control of herbicide resistant strains of black-grass and rye-grass
Moss, S.R
Developing and disseminating decision support tools to the arable sector
Mayes, J.A
Development of population genetic models and statistical methods for inferring parameters
Dawson, K.J
Evolution and characterisation of resistance to ALS inhibiting herbicides in weeds
Moss, S.R
Herbicide resistance management: evaluation of strategies (HeRMES)
Moss, S.R
Herbicide Studies
Glen, D.M
Improving crop profitability by using minimum cultivation and exploiting grass/weed ecology
Moss, S.R
Improving willow breeding efficiency for biomass through the implementation of molecular marker technologies
Karp, A
Integrated control of fungal diseases in willows and poplars for bioenergy
Pei, M.H
Integrated non-fungicidal control of Melampsora rusts in renewable energy willow plantations
Pei, M.H
Management of emergent aquatic and riparian vegetation
Newman, J.R
Methods to diversify field margin plant communities
Marshall, E.J.P
Modelling weed crop dynamics and competition to improve long-term weed management
Cussans, J.W
Novel methods of controlling submerged aquatic vegetation and algae
Newman, J.R
Parameterising the biology and population dynamics of weeds in arable crops to support more targeted weed management
Lutman, P.J.W
Partnership willow breeding
Karp, A
Pest population behaviour in relation to the biological chemistry of willows: towards optimisation of non-chemical control
Karp, A
Population genetics of herbicide resistance in grass-weeds
Karp, A / Moss, S.R
Provision of best practice advice on aquatic and riparian vegetation management
Newman, J.R
Sustainable weed management: development of techniques to balance biodiversity benefits with retention of yields
Lutman, P.J.W
The dynamic nature of introgressive hybridisation in natural and introduced polyploid plants from agricultural and riparian landscapes: An evaluation of molecular tools in willows
Barker, J.H.A
The effects of different crop stubbles and cereal straw disposal methods on wintering birds and arable plants
Marshall, E.J.P
Use of molecular genetics in understanding population biology of key species in arable systems
Karp, A

Invertebrate Population Genetics and Ecology

Denholm, A.I

A review of research into the effects on farmland biodiversity of the management associated with genetically modified cropping systems
Perry, J.N
Agricultural implications of insect population dynamics and the conservation of biodiversity
Woiwod, I.P
An harmonic radar investigation of the navigational performance of honey bees
Woiwod, I.P
Aphid ecology and population dynamics
Harrington, R
Dissemination and exploitation of aphid monitoring data
Harrington, R
Ecological genetics and management of insecticide resistance
Denholm, A.I
Exploitation of aphid monitoring in Europe (EXAMINE)
Harrington, R
Factors influencing resistance proneness and development in aphids
Denholm, A.I
Farm scale studies of GM winter oilseed rape and farmland wildlife
Woiwod, I.P
Field-scale evaluation of GM crops
Marshall, E.J.P
Forces driving changes in spatio-temporal dynamics in the garden tiger moth (*Arctia caja*) over the UK
Perry, J.N
Individual-based spatio-temporal predator-prey dynamics
Perry, J.N
Integrated control of slugs in arable crops
Bohan, D.A
Integrated control of slugs in horticulture
Glen, D.M
Long term trends in insect biomass
Harrington, R
Management of insect pests and viruses of tobacco using ecologically compatible technologies
Denholm, A.I
Modelling the effects on farmland webs of herbicide and insecticide management in the agricultural ecosystem

Perry, J.N
Modelling the spatio-temporal distributions of slugs for scenarios of climate change
Bohan, D.A
Monitoring and management of resistance to neonicotinoids and other insecticides in *Myzus persicae*
Denholm, A.I
Monitoring movement of herbicide resistance genes from farm scale evaluation field sites to populations of wild crop relatives
Woiwod, I.P
Monitoring the response of European populations of *Myzus persicae* to Decamethrin
Denholm, A.I
Natural enemies of arable pests - study of movement and host preferences using molecular markers
Loxdale, H.D
Outdoor lettuce: the control of aphids resistant to insecticides
Denholm, A.I
Population and insecticide resistance dynamics in aphid vectors of beet viruses
Harrington, R
Population genetics of knockdown resistance (kdr) to pyrethroid insecticides in the aphid, *Myzus persicae*
Denholm, A.I
Pyrethroid / OP mixtures for the control of *Helicoverpa armigera*
Devine, G.J
Radar studies on the high altitude movement of aphid predators
Woiwod, I.P
Research into spatio-temporal dynamics for ecological and agricultural populations
Perry, J.N
Sea lice resistance to chemotherapeutants
Denholm, A.I / Devine, G.J
Sustainable control of the cotton bollworm, *Helicoverpa armigera*, in small-scale production systems
Devine, G.J

Insect Behaviour
Powell, W

Behavioural ecology of pollinators
Williams, I.H
Ecological and behavioural side-effects affecting the evolution of insecticide resistance in the aphid *Myzus persicae*
Powell, W
Factors affecting cross-pollination in oilseed rape varieties, particularly low fertility, growing under typical UK conditions
Osborne, J.L
Fungal control of *Varroa destructor*
Ball, B.V
Increasing beneficial insect numbers and diversity in field margins for aphid control
Powell, W
Integrated management of pest and beneficial insects on oilseed rape
Williams, I.H
Integrated pest management strategies incorporating bio-control for European oilseed rape pests (MASTER)
Williams, I.H
MiCo SPA - Microbial control in sustainable peri-urban agriculture in Latin America (Cuba and Mexico)
Pell, J.K
Multitrophic interactions on transgenic plants: Quantifying the risk and determining potential ecological consequences
Pell, J.K
New approaches to studying tritrophic interactions involving resistant transgenic plants
Powell, W
Novel pest and disease control - OSR
Pickett, J.A
Novel strategies for aphid control using entomopathogenic fungi
Pell, J.K
Protocols for laboratory, extended laboratory and semi-field bioassays in pesticide risk assessment schemes for non-target arthropods
Powell, W
Role of foraging behaviour in parasitoid ecology and population structure
Powell, W
Screening pathogens for biocontrol of *Varroa jacobsoni*
Ball, B.V / Pell, J.K
Spatial modelling of *Bombus terrestris* and *B. pascuorum* populations in agricultural landscapes
Osborne, J.L
The control of exotic bee diseases
Ball, B.V
Utilising populations of natural enemies for control of cereal aphids
Powell, W

Chemical Ecology
Pickett, J.A

A strategic approach to the effects of pest and disease management on the dynamics of the species complexes of *Bemisia tabaci* transmitted Begomovirus
Wadhams, L.J
Armoured bush cricket investigations
Wadhams, L.J
Biocontrol approaches to aphid control
Wadhams, L.J
Chemistry of rhizosphere interactions bewteen the legume *Desmodium uncinatum* and the parasitic weed *Striga hermonthica*
Pickett, J.A
Development of effective control methods for the chicken mite (CHIMICO)
Wadhams, L.J
Exploiting knowledge of western flower thrips behaviour to improve the efficacy of biological control measures
Wadhams, L.J
Field studies: semiochemicals and pest/natural enemy dynamics
Pickett, J.A
Identification of semiochemicals of insect pests with potential for minimising use of pesticides in UK crops
Pickett, J.A
Identification of the sex pheromones of prune aphids
Wadhams, L.J
Improving biological control of thrips and aphids on protected ornamentals
Wadhams, L.J
Insect chemical ecology: identification and production of chemical signals (semiochemicals)

Pickett, J.A
Insect chemical ecology: understanding the roles and underlying mechanisms of chemical signals (semiochemicals)
Wadhams, L.J
INSENSE prototypes - Bee sensing systems for volatile indicator molecules
Wadhams, L.J
Integrated control of wheat blossom midge
Wadhams, L.J
NATO Postdoctoral Fellowship
Pickett, J.A
New semiochemical opportunities from *Nepeta spp.* as a non-food crop
Pickett, J.A
Researching strategies for the control of *Culex spp.* mosquitos
Pickett, J.A
Role of wild habitat in the invasion of cereal crops by stem-borers, *Chilo partellus*, *Busseola fusca*, in Africa
Wadhams, L.J

Insect Molecular Biology
Field, L.M

Investigation with piperonyl butoxide as an insecticide synergist in susceptible and resistant strains of vegetables and cotton insect pests
Moores, G.D
Investigations on the molecular mechanisms of flea resistance to insecticides
Williamson, M.S
Molecular analysis of insect nicotinic acetylcholine receptors
Williamson, M.S
Studies of acetylcholinesterase in *Myzus persicae*
Moores, G.D
The molecular basis of responses by insects to semiochemicals
Field, L.M
The molecular basis of target site and metabolic insecticide resistance
Field, L.M

Pesticide Chemistry
Bromilow, R.H

Behaviour of pesticides in the field in sediment / water systems for use in predicted environmental concentrations (PECs) for surface waters
Bromilow, R.H
Circumventing pesticide resistance through chemistry-led approaches
Khambay, B.P.S
Laboratory column investigation of preferential flow of pesticides; particularly the loading and unloading of macropores
Bromilow, R.H

Nutrient Dynamics
Goulding, K.W.T

Advanced terrestrial ecosystem analysis and modelling (A TEAM)
Glendining, M.J
An interactive study on S Cycling and C, N & S interactions in agricultural ecosystems
McGrath, S.P
Application and development of a UK nitrous oxide emission model
Goulding, K.W.T
Assessing the role of dissolved and particulate organic matter (DON/PON) in N cycling within natural, semi-natural and agro eco-systems in the UK
Goulding, K.W.T
Assessment of P leaching losses from arable land
Brookes, P.C
Atmospheric deposition and its impact on ecosystems
Goulding, K.W.T
Carbon and nitrogen transformations in soils
Goulding, K.W.T
Development of a prototype soil nitrogen supply calculator
Goulding, K.W.T
Environmental benchmarks of arable farming
Goulding, K.W.T
Framework to evaluate farm practices to meet multiple environmental objectives
Goulding, K.W.T
Harnessing tillage x nutrient management interactions using participatory approaches to improve rice wheat systems productivity and sustainability
Gaunt, J.L
How far will medium term weather forecasts improve assessment of risks?
Glendining, M.J
Improving the physiological and agronomic basis of UK lupin production
Shield, I.F
Increasing the efficiency of phosphate fertiliser use
Brookes, P.C
LIFE - The effect of ploughing after non-inversion tillage
Donaldson, G
Livelihoods improved in Bihar and Uttar Pradesh
Gaunt, J.L
Long-term experiments in nutrient cycling research
Powlson, D.S
Long-term sustainability of cereal yields
Goulding, K.W.T
Modelling nitrogen fluxes in tundra ecosystems on Svalbard
Poulton, P.R
Paradigms for modelling environmental systems
Whitmore, A
Soil microbial, organic matter and nutrient interactions
Brookes, P.C
Strengthening rural services for improved livelihoods in Bangladesh
White, S.K
Sulphur dynamics in the soil/crop/atmosphere system
Zhao, F.J
Technology transfer: effective nutrient use for arable crops
Goulding, K.W.T
The Coates Farm Study II - Nitrogen flows in a changed mixed farming study
Goulding, K.W.T
The impact of land management practice on the global warming potential (GWP) of UK agriculture
Goulding, K.W.T
Using long-term experiments to study the sustainability of agroecological systems

Poulton, P.R
Using the PSALM model to interpret the phosphate change point and its relation with iron in the soil
Addiscott, T.M

Nutrient Acquisition
Hawkesford, M.J

A novel method for diagnosis of S deficiency and its development as a practical tool for routine testing
BlakeKalff, M.M.A
Does soil mechanical impedance cause changes in plant gene expression?
Hawkesford, M.J
Dynamics of nutrient pools in plants and their relationship to crop growth, yield and quality
Barraclough, P.B
Effects of nitrogen supply on the wheat endosperm transcriptome
Hawkesford, M.J
Establishing the potassium requirements of modern, high yielding sugar beet crops for yield and beet quality
Barraclough, P.B
Optimising nutritional quality of crops
Hawkesford, M.J
P diagnostics for oilseed rape crops
Barraclough, P.B
Plant use of nitrogen (PLUS N) research training network
Miller, A.J
Regulation of sulphate transporter gene expression and sulphur metabolism in cereals, source-sink interactions and sulphur supply to grain tissues
Hawkesford, M.J
Smart plant technology for sensing crop nutritional status
Hawkesford, M.J
Soil sensors for nitrogen availability
Miller, A.J
The cell biology of nitrogen acquisition and allocation
Miller, A.J

Soil Protection and Remediation
McGrath, S.P

Development of a predictive model of bioavailability and toxicity of copper in soils
McGrath, S.P
Development of a predictive model of bioavailability and toxicity of nickel in soils
McGrath, S.P
Effects of inorganic metal salts on soil microbial activity
McGrath, S.P
Effects of metal salts on soil fertility - Phase III
Chaudri, A.M
Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long-term soil fertility
Chaudri, A.M
Effects of sewage sludge applications to agricultural soils on soil microbial activity-implications for agricultural productivity and long term soil fertility - Phase II
Chaudri, A.M
Effects of sewage sludge on long term soil fertility: Phase III
Chaudri, A.M
Effects of Zn contamination on soil microbial processes
McGrath, S.P
Evaluation of the factors controlling selenium and cadmium uptake by cereal crops
Zhao, F.J
Identification of genes involved in cadmium hyper-accumulation in a higher plant, *Thlaspi caerulescens*
Hawkesford, M.J
In situ remediation of industrial soils using red mud
McGrath, S.P
International project for the remediation and inactivation of metals *in situ* (IMPRIMIS)
Lombi, E
Phytoremediation of contaminated soils
McGrath, S.P
Research on assessment of polluted soils and their remediation
McGrath, S.P
Research on assessment of polluted soils and phytoremediation
McGrath, S.P
Rhizoremediation of land contaminated with persistent organic pollutants; elucidation manipulation and modelling of the processes involved
McGrath, S.P
Selection of plant genotypes from Kazakhstan flora contributing to alleviation of heavy metal hazard to human and animal health
McGrath, S.P
Soil protection and remediation by chemical and biological approaches
McGrath, S.P

Carbon Cycling
Powlson, D.S

Agronomy of reed canary grass and switchgrass
Christian, D.G
Dynamics of organic carbon in soil
Powlson, D.S
Enviros composting project
Brookes, P.C
Evaluating grasses as a long term energy resource
Christian, D.G
GM impacts on the soil gene pool, microbial activity and diversity
Hirsch, P.R
Governing a trial of the suitability of switchgrass and reed canary grass as a bio-fuel crop under UK conditions
Christian, D.G
Microbial function in nitrogen and carbon transformations
Gaunt, J.L / Powlson, D.S
Provision of information on crops with potential use as a biofuel
Powlson, D.S
Soil carbon fluxes and land use change: modelling component for national carbon dioxide inventory
Falloon, P.D
Soil microbe diversity and activity
Hirsch, P.R
STAMINA - Stability assessment for arable land use on sloped terrain under increased climatic variation
Richter, G.M
The hydrological impacts of energy

crop production in the UK
Christian, D.G
To develop a robust indicator of soil organic matter status
Gaunt, J.L
UK emissions by sources and removals by sinks due to land use, land use change and forestry activities
Falloon, P.D / Smith, P
Understanding the paradox of organic matter mineralization
Brookes, P.C

Biomathematics
Thompson, R

A rational design basis for design of wheat canopy ideotypes for UK environments
Semenov, M.A
A strategic approach to the effects of pest and disease management on the dynamics of the species complexes of *Bemisia tabaci* transmitted Begomovirus
Van Den Bosch, F
Analysis of transient weed dynamics in environments with periodic change and its application to weed population dynamics in crop rotations
Van Den Bosch, F
Application of non-linear mathematics and stochastic modelling to biological systems
Semenov, M.A
Appropriate dose network: new fungicide performance information for wheat growers
Verrier, P.J
Assessing predictive skills of crop models to optimise crop management in the UK
Semenov, M.A
Communicating variety recommendations in the 21st century
Thompson, R
Development of algorithms for the design and analysis of biological experimentation
Payne, R.W
Extension of systems of genetic improvement
Thompson, R
INTEREST (Interaction between the environment, society and technology)
Riley, J
Investigate and develop different modelling approaches in extending understanding and quantification of biological systems
Van Den Bosch, F
Modelling approaches with applications to modelling dispersal and gene flow in populations
Thompson, R / Van Den Bosch, F
Modelling life-history / dispersal-strategy interactions to predict persistence and diversity in agricultural landscapes
Thompson, R
Monte Carlo methods for detecting and using interacting quantitative trait genes
Thompson, R
Representative Soil Survey Scheme
Thompson, R
Research in statistics relevant to biological processes
Thompson, R
Risk assessment for biological control of pest slugs using a slug parasitic nematode
Semenov, M.A
Transgene induced life history changes and the ecology of GMO crops
Van Den Bosch, F
VSN - Visualisation, Statistics and Numerics
Payne, R.W

Sugar Beet Improvement and Production
Pidgeon, J.D

A drought tolerance screen for existing beet varieties: adding value to NIAB variety trial results
Pidgeon, J.D
A novel approach to achieve tissue specific transgene expression in plants
Mutasa-Göttgens, E.S
Assessing drought risks for UK crops under climate change
Mitchell, R.A.C
Biotechnological approach to improved control of quality, pest and disease traits in sugar beet
Mutasa-Göttgens, E.S
Botanical and Rotational Implications of Genetically modified Herbicide Tolerance (BRIGHT)
Lutman, P.J.W / May, M.J
Competition review: Recent progress in sugarcane research, breeding and production practice by majoy sugar exporters
Pidgeon, J.D
Demonstration of headland management options to enhance the environment around UK sugar beet fields - 2002/2003
May, M.J
Effect of weed management on crop yield, weed growth and seed production and invertebrate presence in glyphosate tolerant sugar beet
Dewar, A.M / May, M.J
Energy and environment impact assessment for sugar beet production systems
Jaggard, K.W
Forecasting the yield of the sugar beet crop
Jaggard, K.W
Frost protection for beet in the field
Jaggard, K.W
High resolution meteorological data to support improved decision making and increased profitability in sugar beet production
Jaggard, K.W
Improving the drought tolerance of sugar beet
Ober, E
Nitrogen nutrition of the sugar beet crop
Jaggard, K.W
Physiology of beet growth during autumn
Jaggard, K.W
Predicting changes in the sugar content of delivered beet during the processing campaign
Jaggard, K.W
Production of growers advisory guide and information database
May, M.J
To assess the effect of direct drilling on invertebrate diversity (soil microfauna, earthworms and carabid beetles) in glyphosate-tolerant sugar beet treated with conventional herbicides and glyphosate applied overall or in a band over the rows
Dewar, A.M

Sugar Beet Protection
Asher, M.J.C

Addressing the need for disease resistant sugar beet seed
Asher, M.J.C
Assess the effect of late control of weeds in glufosinate-tolerant sugar beet on arthropod diversity
Dewar, A.M
Biological control of seedling diseases
Asher, M.J.C
Co-ordination of the BBRO education programme
May, M.J
Comparative analysis of genes induced by Polymyxa in incompatible and non-host interactions
Asher, M.J.C
Mutasa-Göttgens, E.S
Control of late season foliar diseases
Asher, M.J.C
Drought stress in *Beta spp.*
Pidgeon, J.D
Ecology and control of sporadic pests of sugar beet
Dewar, A.M
Efficacy and environmental impact of neonicotinoid seed treatments
Dewar, A.M
Evaluation of sugar beet resistance to beet mild yellowing luteovirus
Smith, H.G
Evaluation of sugar beet resistance to beet yellows closterovirus and beet mild yellowing luteovirus
Stevens, M
Horizontal gene transfer - a role for Plasmodiophoromycete root parasites
Mutasa-Göttgens, E.S
Investigate effects of glyphosate tolerant beet on biodiversity
Dewar, A.M
Molecular Luteovirology: Understanding cell-to-cell movement
Stevens, M
New sources of disease resistance from Beta germplasm
Asher, M.J.C
New sources of rhizomania resistance
Asher, M.J.C
The development of rhizomania resistance for the UK
Asher, M.J.C
The monitoring and control of rhizomania in the UK
Asher, M.J.C
The plant clinic at Broom's Barn
May, M.J
Virus yellows control: Characterisation of virus strains
Stevens, M
Virus yellows control: diagnostic methods
Stevens, M
Virus yellows control: forecasting and spray warning scheme
Stevens, M
Virus yellows control: Transgenic resistance to yellowing
Stevens, M

Financial Report

INCOME AND EXPENDITURE

The Institute reports a deficit for the year of £171,385 (2002 deficit of £125,000) after charging exceptional staff redundancy and early retirement costs of £50,000 (2002 £429,000) but before setting aside amounts for capital investment in buildings and major equipment.

Income from research activities at £23.6m (2002 £23.6m) was static in monetary terms. Allowing for higher income payable to sub-contractors in 2003 as compared with 2002, research income retained by the Institute fell to £21.4m in 2003 from £21.8m in 2002. In real terms (inflation adjusted) this represents a decrease of approximately £1 million. Other income at £2.0m (2002 £2.8m) fell as income from ancillary activities at Long Ashton were scaled back and as bank deposits were reduced to assist the financing of the Rothamsted site-redevelopment programme.

Staff costs at £16.2m (2002 £17.3m) were reduced reflecting staff losses including non-renewal of contracts. Posts at Long Ashton, in particular, have been decreasing during the course of the year in preparation for the final relocation of activities to Rothamsted early in the next financial year.

Against the background of a fall in real staff costs in the year of approximately £1.8 million Institute management is satisfied that those who generate income in research groups have been able to hold the reduction in real research income to approximately £1 million. This satisfaction is tempered by the fact that a fully sustainable business model for the future is not yet constructed and implemented. Simply to maintain the existing buildings and technical facilities requires the Institute to set aside not less than £2m per annum, a target that should be achieved, pre deductions for exceptional costs, immediately following the re-structuring in 2003. Thereafter, however, it will only be achieved if income keeps pace with cost growth in real terms.

Stated in £000's

	2003 unaudited	2002	2001	2000	1999	1998
INCOME						
BBSRC Grant-in-aid	8507	8259	8202	8203	8925	8824
Competitive research grants:						
BBSRC	2731	2342	1795	1917	1786	1739
DEFRA – including Commissions	6311	6007	6245	6443	6822	7590
European Union	1230	1228	1478	1993	2198	1544
Industry and levy bodies	3176	3431	3662	3210	3630	2996
Government departments	1240	2192	2076	1010	932	1109
Other grant making bodies	379	190	131	640	772	836
Total competitive research grants	15067	15390	15387	15213	16140	15814
Other income	1975	2768	3232	2526	2404	3110
Total income	**25549**	**26417**	**26821**	**25942**	**27469**	**27748**
EXPENDITURE						
Staff costs	16202	17292	17170	17062	18015	17457
Research sub-contractors	2167	1776	1324	906	1197	1118
Laboratory supplies	1931	1635	1795	2051	1946	1832
Utilities and space costs	1348	1206	1272	1179	1012	1045
Repairs and maintenance	648	662	710	791	731	678
Other costs	3374	3542	3749	3627	3373	3081
Exceptional staff costs	50	429	213	251	0	0
Total costs	**25720**	**26542**	**26233**	**25867**	**26274**	**25211**
Surplus/-deficit for year	**-171**	**-125**	**588**	**75**	**1195**	**2537**

CAPITAL EXPENDITURE

Works to complete the construction of new Laboratory (to be known as the Centenary Building) at a cost of approximately £18.5m before VAT have progressed significantly during the course of the year. Minor delays in the completion of this important project have not, thus far, pushed cost projections beyond the level set aside by the Board in 2000. All other projects that have been completed as part of the Rothamsted re-development programme have been constructed on time and within cost budget.

Significant expenditure is still required to bring Rothamsted's facilities fully up to date and the Institute is grateful for the support that it has received from the BBSRC and, recently, from the East of England Development Agency, towards the cost of the full modernisation programme.

Corporate Governance

The Institute is constituted under the terms of a 1994 Co-operation Agreement entered into by Rothamsted Research Limited (previously known as Rothamsted Experimental Station), the University of Bristol, Lawes Agricultural Trust Company Limited and Arable Research Institute Association (formerly the National Fruit and Cider Institute). Under the terms of the Co-operation Agreement, the signatories agreed to co-operate in the operation of the Institute.

Following the relocation of the activities of Long Ashton Research Station to Rothamsted in the spring of 2003 the governance of the Institute's affairs will, thence forward, fall under the responsibility of the Board of Directors of Rothamsted Research. Until then, the governance of Long Ashton will remain in the hands of the University of Bristol, guided by the Director of Long Ashton.

Membership of the Board of Directors of Rothamsted Research, which has standing meetings three times a year, comprises 14 directors. Six directors are nominated by LATCo, five are nominated by the Biotechnology and Biological Sciences Research Council, one is nominated by the National Farmers Union, and one by the Scottish Executive for Environment and Rural Affairs Department (SEERAD). The Chairman is jointly appointed by LATCo and the BBSRC.

Members of the Governing Bodies are bound by confidentiality and, in the case of Rothamsted Research, by the terms of a Code of Conduct and Register of Directors Interests. The Chairman of the Board acts as the staff Ombudsman.

The Board of Directors of Rothamsted Research has established three sub-committees; the Audit Committee, which meets three times a year, is charged with considering all business critical risks, health and safety issues and with monitoring financial reporting and accounting and control standards generally. Membership of the committee comprises four directors who are appointed in rotation at two yearly intervals, advised by representatives of the external and internal auditors and by members of the general and financial management of the Institute. The Rothamsted Site Re-Development Sub-Committee, which comprises two members of the Board and internal and external advisers, monitors the performance of the business critical site re-development project and reports its findings to the Board and to the Audit Committee. The Director's Research Advisory Group comprises scientist members of the Board and it meets with the Director and Heads of Division, as required, to address specific scientific issues.

COMMERCIAL ACTIVITIES

The development of commercial activities in Rothamsted Research has continued despite the necessary pre-occupation of management with the re-organisation of the Institute and the re-development of the Rothamsted site.

Insense Limited

Insense Limited is a spinout from Unilever Colworth that utilises Rothamsted Research know-how in bee behaviour technology. Rothamsted holds a 6% equity stake in this start-up venture. Market applications for technologies developed by the company may lead, in the coming year, to the establishment of companies that address specific market opportunities.

VSN International Limited

The management of VSN International has a clear view of the company's future as a data analysis solutions provider and the key drivers that will convert potential into success. One of these drivers, the need for operating efficiency, has resulted in the small team of nine consolidating their activities in premises at Hemel Hempstead. This has overcome the cultural and operating inefficiencies of a team spread across two not-for-profit locations.

The principal funder of VSN International, the Numerical Algorithms Group of Oxford, has sustained a cyclical downturn in its business (the provision of algorithms to software developers). As a consequence NAG has had difficulty meeting its full loan finance obligations to VSNI on a timely basis so Institute management is working with all the stakeholders in this promising venture to raise second round development capital.

Trading results to date, at the result before taxation line, are within business plan but, due to the inability of the management of VSNI to invest in key drivers, the result has been achieved on lower sales and lower costs than planned.

The Lawes Agricultural Trust

Sir John Bennet Lawes, with Sir Joseph Henry Gilbert, established Rothamsted Experimental Station (now known as Rothamsted Research) in 1843. In 1889, with one third of the proceeds of the sale of his fertiliser business, Sir John Bennet Lawes established and endowed The Lawes Agricultural Trust (with £5 million in today's money). The Trust operated the Station, now Rothamsted Research, from 1889 to 1990.

In 1934, the Trust purchased the freehold interest in the Rothamsted Estate. Following later additions, the property interests of the Trust grew to comprise 330 hectares at Harpenden – the Rothamsted Estate – which includes an experimental farm and Rothamsted Manor (Grade 1 listed), residential houses and flats and commercial properties. At Higham in Suffolk, the Trust owns the freehold interest in the 77-hectare Broom's Barn Experimental Station.

In 1990, the business and undertaking of the Station was transferred from the Trust to a separate charitable company of the same name. In 1991, the employees of the Station became employees of the Agriculture and Food Research Council, now the BBSRC. In December 2002 the Station changed its name to Rothamsted Research Limited.

The main present day role of the Trust is to provide support for Rothamsted Research in a number of ways. It provides an annual research grant to the Director under a research policy agreed with the Trustee in 1997 and it provides 170 beds, in differing housing combinations, for the use of staff, students and visiting workers. The Trust also operates Rothamsted International, a subsidiary charity which exists to provide the opportunity for scientists from anywhere in the world, but particularly from developing countries, to share their expertise within the advanced, multi-disciplinary research environment at Rothamsted. The Trust also makes capital grants to complete and to modernise ancillary facilities at Rothamsted – for example, the Trust has in the past year provided funds to assist the refurbishment of the Rothamsted library (including the provision of an environmentally controlled rare books store) and it has committed to spending more than £1 million on the refurbishment and provision of additional residential accommodation. The Trust has its own non-charitable interests that are dedicated, mainly, to sustainable agriculture in developing countries through a joint venture active investment company, Biii Limited, formed jointly with Hertfordshire Business Link in December 2002.

Staff of the Institute as at 31 March 2003

INSTITUTE DIRECTOR AND DIRECTOR OF ROTHAMSTED

Professor Ian R Crute

Personal Assistant: Sue C McCartney

Associate Director:

Professor Brian R Kerry

Personal Assistant: Deirdre F Hughes

ASSOCIATE DIRECTOR AND DIRECTOR OF LONG ASHTON

Professor Peter R Shewry*

Personal Assistant: Pat A Baldwin

DIRECTOR OF BROOM'S BARN

John D Pidgeon

Personal Assistant: Sue Frampton

Staff with functional responsibilities throughout the Institute:

Institute Secretary **Peter S Thomas**

Institute Assistant Director, External Relations **Stephen James**

Institute Assistant Secretary and Head of Administration Michael J Truelove[1]

Institute Administrative Computing Manager Trevor O Pocock

Institute BioInformatics Paul J Verrier

Institute Biomathematics Robin Thompson

Institute Computing Manager Gavin E Harrison

Institute Contracts Manager Tina L Alger

Institute Engineer Mike J Hadlow

Institute Financial Accountant Andrew J Allan

Institute Management Accountant Nicholas C Skinner

Institute International Liaison and PR Susannah M Bolton

Institute Librarian Liz Allsopp

Institute Personnel Officer Tony Jowett

Institute Purchasing Manager Richard W M Lilley

Institute Safety Officer Cliff P Brookes

AGRICULTURE AND THE ENVIRONMENT DIVISION

Head of Division

K W T Goulding BSc, MSc, PhD, FISoilSci, *Special Professor in the School of Life and Envrionmental Sciences, University of Nottingham; Visiting Lecturer in the Department of Soil Science, University of Reading*

Personal Assistant: C H Jaggard

Secretaries: D P Dawkins, A C Piears[1]

Typists: M McDonnell[1], H M Richardson BSc[1]

Admin: K L Harwood

Nutrient Dynamics

K W T Goulding

T M Addiscott[1] MA, PhD, DSc *Visiting Professor in the Department of Environmental Sciences and Mathematics at the University of East London*

R H Cartwright[1] BSc

A G Dailey

S Fortune BSc, MSc, PhD

S M J Francis BSc

N Gilbert[1]

M J Glendining MA, PhD

P R Hargreaves BSc

S Kerley[1] BSc, PhD

P K Leech[1] BSc

A J Macdonald BSc, PhD

S M Mitchinson[2] BSc

P R Poulton

T Scott

E A Stockdale BSc, PhD

A J Swain BSc

G Tuck BSc

C P Webster BSc, MSc

S K White BSc, PhD

Soil Protection and Remediation

S P McGrath BSc, PhD *Honorary Professor in the School of Biological and Earth Sciences, Liverpool John Moores University; Special Professor in the School of Life and Environmental Sciences, University of Nottingham*

M Blake-Kalff[1] MSc, PhD

N F Caille[2] PhD

C M Falloon BSc

A M Chaudri BSc PhD

M R H Davis[2] BSc, MSc

P G Dennis[2] BSc

S J Dunham

M A Fox[2] BSc, MSc, PhD

D L Johnson PhD

M Moreau[1]

C P Rooney[2] BSc, PhD

B Tenet[1]

F-J Zhao BSc, MSc, PhD

Carbon Cycling

D S Powlson BSc, PhD *Visiting Professor in the Department of Soil Science, University of Reading*

D Abaye[1] PhD

P C Brookes BSc, PhD, DSc *Honorary Professor of Soil Science in the School of Natural and Environmental Sciences, University of Coventry; Honorary Professor at the Institute for Tropical Agriculture, Changsha; Honorary Professor at the Northwest Sci-Tech University of Agriculture and Forestry, Yangling, China; Honorary Professor at the Agricultural University of China, Beijing*

D G Christian BSc

K W Coleman BSc MSc

P D Falloon BSc, MSc

J L Gaunt BSc, PhD

C A Grace

S J Kemmitt[2] BSc, MSc, PhD

D P B Perocheau[1]

G Richter PhD

S P Sohi BSc, MSc, PhD

A P Whitmore PhD

H C Yates BSc

Biomathematics Unit

R Thompson BSc, MSc, DSc, FRSE
Visiting Professor in School of Mathematical Sciences, Queen Mary and Westfield College, University of London; Special Professor in the Department of Mathematics, University of Nottingham
G M Arnold[1] BA, MSc *Research Fellow**
A Baierl
I Beardmore
M Cherry[1]
Y H Choi BSc, MSc, PhD
D Claessen PhD
S J Clark BSc
P D Fisher[1]
S A Harding BSc
H E Jones PhD
C Lawless PhD
S K Mertens[2] BA, MA, MSc, PhD
V J Mitchell
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J Yanai (Japan)
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S J Cookson
I M Demon
S Machefert
S P Pandey
S Parnell
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A V Reed[2]
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A C Brown
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Pathogen Population Biology and Disease Management

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C J O Winfield
P A Wiseman
B H Wright[2]

Human Resources
Head of Human Resources: **A Jowett[4]**

Rothamsted HR Manager:
J M Heggie
S H Brooker
J Clark
A M Hurd[2]
S J Laidler
E L J Wallsgrove

Purchasing Management
R W M Lilley[4] (*Institute Purchasing Manager*)
R J Barlow
S J Flay
M R Hylands
A-M McCann
K Sharma
R D Wiltshire

Conference, Restaurant, Accommodation and Properties
Rothamsted Manor Ltd
K B Bowen, General Manager

Rothamsted Manor
M Grundy[1]
M D Hanley[1]
J A Haynes[2]
G A Healy
G Hughes[2]
A Major
L C Pollock
S Seaborn
K S Shields[2]
J A Watson

Rothamsted Conference Centre
O A Abere
Y A Anderson[1]
R A Arnold[1]
H M Cartmell[2,1]
A Fensom
N Graham[2]
S A McKeegan[2]
C V Minall[1]
S J Morrison[2]
C O'Keeffe[2]
R H Woodford-Smith[2,1]
M A Woollard

Safety
C P Brookes[4]

Secretary: J M Tuck

Visiting Workers
R Atkin
R H Clarke
A King
P Loveland
J H Stevenson

Long Ashton Finance, Facilities and Human Resources
Head of Finance and Administration:
J M de Borde FCMA
Secretary: C M Scott

Finance
D K Davis
L E Hartley
A C Hendrick MAAT
R C G Villis
G A Wilton[1]

Human Resources
F M Cowles Grad IPD
J F Holmes
L J Roome

Safety
L R Saker BSc (*Long Ashton Radiation Protection Supervisor – HS*)

Post and Telephones
P Harris[1]
V E Johnson

Purchasing and Stores
W B Johnson

Refectory
J E Blakeway
J Y Rogers[1]
G H Schafer

Cleaners
C S Ambrose
S D Cherrington
B D Cheshire
C A Collins[1]
M K Cook[1]
J A Gray[1]
M Hughes[1]
N Jarvis[1]
M W Lewis
E J Sandford

Facilities Department
Institute Engineer
M J Hadlow[4] BSc

Rothamsted Facilities
Head: **M J Hadlow[4] BSc**
Station Engineer: **K Law I Eng MIIE, AMCIBSE**
Admin: P M Evans
S Leaper[1]

Building Services
M Mooring (*Building Supervisor*)
T R Chalkley
T F Dimmock[2]
T J Hucklesby
K A Rowe[2,1]

Security
N B Maud (*Security Supervisor*)
M W Brown
S Harvey
B P Haward
P J Hughes

Technical Support Services
A J Flay (*Technical Support Services Manager*)
M C Byrne
A J Fox
R Garnett

A G Hobbs (*Development Supervisor*)
D Hardwick
R Horsler
N Maher

T D Edwards (*Electrical and Mechanical Services Supervisor*)
B J Newins (*Vehicle Technician*)
D G Reader
G J Wright

R L Humphreys (*Refrigeration/CE Supervisor*)
R W French
R Greener

Post and Telephones
E Godfrey
P E M Hanson[2]
P M Hull
W V McGrath[2]
C A Weston

Site Redevelopment Project
R J Taberer, MI Plant E *(Projects Engineer)*
R J Mahoney *(Clerk of Works)*

New Laboratory Project
S Takla BSC, BArch, MSc, RIBA *(Project Manager)*
C van de Putten MSc *(Assistant Project Manager)*
Admin Support: K L Morris

Long Ashton Facilities

Head: **M R E Williams**
Deputy: S C King FSc, CEng, MIEE
Office Administrator: L C Lasseter[1]

Building
R M Jones[1]
C R Lloyd

Electrical Engineering
C J King[1]

Mechanical Engineering
D W Newman
P J Arnel[1]

Instruments
R S Cole[1] IEng (CEI), MIMechIE

Electronics
B Kelly[1]
R Hill[1]

Controlled Environment
P R Turner[1]

Transport
K Rudd[1]
M A Ward[1]

FARMS

Head of Farms: **C G Peters, BSc**
Secretary: A E Talbot

Quality Assurance
P A Cundill
D P Yeoman BSc

Rothamsted Farm
G N Talbot
M O Gardner
M W Egginton[1]
C J Hall
T Hall
M N Rogers
K L Sykes BSc
P J Tuck

Farm workers
F D Ledbury

Woburn Farm
A M Hunt
T J H Battams
P M Pope

HORTICULTURAL AND CONTROLLED ENVIRONMENT

Head of Department
J Franklin BSc
Personal Assistant: D P Dawkins

Controlled Environments
I Pearman BSc
R J Burningham[1]
L J Dawson
A S Griffin
R G Parkinson

Glasshouses
A J Callewaert
F Gilzean
S C Harvey BA
A W Jones
J A Maple
K Plumb HNC
M Preston

Grounds
W W Bothwell
E J Blackie
K M Cole[2]
M G Picton
K E Rydlewski

Manor Gardens – Volunteer
H Oliver

Long Ashton
MSc Course in Crop Protection

N J Pinfield BSc, PhD *Senior Lecturer, Biology Department (Course Director)*

Intake Students 2001/2002
L Ashby
R Collins
O Domfeh
F Gonzalez Arizmendi
J Melichar
H Pinfield-Wells
C Poulter
B Swale
C Wright
M-L Yap

[1] Left during 2002/2003
[2] Appointed during 2002/2003
[3] Deceased
[4] Staff with functional responsibilities throughout the Institute
* Academic status at Bristol University