Scottish Crop Research Institute

Annual Report 2002/2003

Governing Body

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The Scottish Crop Research Institute (SCRI) is a major international centre for research on agricultural, horticultural and industrial crops, and on the underlying processes common to all plants. It aims to increase knowledge of the basic biological sciences; to improve crop quality and utilisation by the application of conventional and molecular genetical techniques and novel agronomic practices; and to develop environmentally benign methods of protecting crops from depredations by pests, pathogens and weeds. A broad multidisciplinary approach to research is a special strength of the Institute, and the range of skills available from fundamental studies on genetics and physiology, through agronomy and pathology to glasshouse and field trials is unique within the UK research service.

Das SCRI ist ein führendes internationales Forschungszentrum für Nutzpflanzen im Acker- und Gartenbau sowie in der Industrie und auf dem Gebiet der allen Pflanzen zugrundeliegenden Prozesse. Es hat sich zum Ziel gesetzt, die Grundkenntnisse in den Biowissenschaften zu vertiefen; die Qualität und Nutzung der Kulturpflanzen durch die Anwendung konventioneller und molekular-genetischer Techniken und neuer agrarwissenschaftlicher Praktiken zu verbessern; sowie umweltfreundliche Methoden zum Schutz der Pflanzen gegen Verlust durch Schädlinge, Pathogene und Unkräuter zu entwickeln. Ein breiter multidisziplinärer Forschungsansatz ist eine besondere Stärke des Instituts; und das zur Verfügung stehende Spektrum an fachlichen Ausrichtungen, das von genetischer und physiologischer Grundlagenforschung über Agrarwissenschaften und Pathologie bis zu Gewächshaus- und Feldversuchen reicht, stellt ein einmaliges Forschungsangebot auf den Britischen Inseln dar.

Le SCRI est un centre international majeur de recherche sur les cultures agricoles, horticoles et industrielles et les processus fondamentaux communs à toutes les plantes. Son but est d'accroître les connaissances des sciences biologiques fondamentales; d'améliorer la qualité et l'utilisation des cultures par l'utilisation de techniques conventionelles et de génétique moléculaire et par l'application de procédés agronomiques nouveaux; de développer des méthodes de protection moins dommageables pour l'environnement contre les préjudices causés par les ravageurs, les pathogènes et les adventices. L'une des forces majeures de l'institut est une large approche multidisciplinaire de la recherche. L'éventail des techniques disponibles allant des études fondamentales en génétique et physiologie en passant par l'agronomie et la phytopathologie jusqu'aux essais en serres et aux champs est unique au sein du service de recherche du Royaume Uni.

Lo SCRI e' uno dei maggiori centri internazionali nel campo della ricerca sulle colture agricole, orticole e industriali e sui meccanismi fondamentali comuni a tutte le piante. L'Istituto ha come obiettivo principale l'accrescimento del livello di conoscenza delle scienze biologiche fondamentali, il miglioramento della qualità e del potenziale di utilizzo delle colture tramite l'applicazione di tecniche convenzionali o di genetica molecolare e di nuove pratiche agronomiche, lo sviluppo di metodi ecologici di protezione delle colture da agenti patogeni o malerbe. Uno dei punti di forza dell'Istituto e' l'adozione di un approccio largamente multidisciplinare (probabilmente senza eguali nel servizio di ricerca britannico) fondato su una vasta gamma di capacità scientifiche derivanti da ricerche di fisiologia e genetica ma anche di agronomica e fitopatologia supportate da prove di campo o in ambiente controllato.

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Introduction by the Director

John R. Hillman

The Scottish Crop Research Institute (SCRI) is a non-profit company limited by guarantee, and is a registered charity. The programme of research is funded, in the main, by the Scottish Executive Environment and Rural Affairs Department (SEERAD), together with grants and sponsorship from external sources. The Institute operates from land owned by and rented from the Scottish Ministers, and the majority of the buildings and equipment used by the Institute are funded by capital grant from SEERAD. The relationship between the Institute and SEERAD is set out in the Department's Management Statement and this, along with the Department's Financial Memorandum, sets out the main terms and conditions attaching to the provision of grant-in-aid and capital funding, reflecting the special relationship between SEERAD and the Institute. The Management Statement designates the Institute Director as Accounting Officer, with all the responsibilities that attach to that position, and requires the Institute to apply the Biotechnology and Biological Sciences Staff Code for all staff. SEERAD approval is required for the Corporate Plan, the Business Plan (including the financial and manpower budget), major capital expenditure, the appointment of all senior staff at band 3 and above, including the appointment of the Institute Director and the funding of early retirements and redundancies. Staff are not formally civil servants, but are members of the Scottish Executive Rural Affairs Department Superannuation Scheme, 1999. The Institute may not set up, or dispose of, subsidiary companies without the permission of SEERAD and may not dispose of any grant-funded assets without the permission of SEERAD.

As Accounting Officer, the Institute Director is accountable to the Accountable Officer of the Institute's sponsoring Department (SEERAD) and is responsible for preparing accounts in accordance with relevant directions issued by SEERAD and for arranging for these accounts to be audited in accordance with the relevant provisions of the Management Statement and Financial Memorandum issued by SEERAD. The responsibilities also include ensuring that: (a) the financial management procedures and systems of the Institute are operated correctly and with propriety; (b) they promote the efficient and economic conduct of business; (c) there are adequate safeguards against misuse, wasteful, or fraudulent use of monies including an effective system of internal audit; (d) value for money from public funds is secured; (e) spending proposals are appraised carefully; (f) all expenditure is related to the achievement of clearly defined objectives, firm targets, and effective performance measures, as set out in the Institute's Corporate Plan; (g) there is close observance of the delegated authorities set out in the grant-in-aid Management Statement or Financial Memorandum or terms and conditions attached to capital grant. As Accounting Officer, the Institute Director must be satisfied that, throughout the year, SEERAD funds have been applied in accordance with all conditions relating to those funds.

Following publication in June 2001 of the Scottish Executive report *Public Bodies: Proposals for Change*, the Institute, along with the other four Scottish Agricultural and Biological Research Institutes (SABRIs), was declassified as non-departmental public body on 31st March 2003. Since that date and the loss of NDPB status, SCRI is termed a public-sector research establishment or government-sponsored research institute. The Institute continues to be funded by SEERAD but the Scottish Ministers are no longer responsible for the appointment of the Chairman or the Governing Body members. These changes required alterations to the Institute's Memorandum and Articles of Association, which were approved by the Governing Body on 24 March 2003. In addition, new appointment procedures for Governing Body members have been set out in an Appointment Code of Practice, which is based upon the Commissioner for Public Appointments Code of Practice for Ministerial Appointments to Public Bodies. The Code sets out the desired composition of the Governing Body, along with a framework for the appointments of members that a) aims to provide a clear and concise guide to ensure a fair, open, and transparent appointments process that produces a quality outcome and can command public confidence, and b) is designed to ensure that the Governing Body is representative of the Institute's research programmes, its end-user interests, and stakeholder groups. This code was approved by SEERAD and adopted by the Governing Body on 16 April 2003.

The Institute's Memorandum and Articles of Association contain references to the powers of the Scottish Ministers, in addition to the specific conditions noted in the Management Statement. The Institute requires the approval of the Scottish Ministers to alter the Memorandum and Articles of Association, to apply for and accept any grants of money or property, to acquire any patent rights, and to borrow or invest funds. The approval of the Scottish Ministers is also required for the disposal of any surplus, following the winding up or dissolution of the Institute.

The Institute is committed to the implementation of Corporate Governance, which requires the highest standards in the three key areas of openness, integrity, and accountability. The Governing Body has a Code of Practice to guide the conduct of its members and has established the appropriate procedures and remits to ensure adherence to these standards.

The Mission of SCRI is:
"To be Europe's leading centre for strategic and applied research into plant and crop-based bioscience, and related environmental sciences, creating knowledge, added-value and new products to benefit the food, drink, agriculture and related industries, the bioindustries, and the environment".

Our specific strategic objectives to achieve this Mission are given in Table 1.

SCRI was established in 1981 by an amalgamation of the Scottish Horticultural Research Institute (SHRI, founded at Invergowrie, Dundee in 1951) and the Scottish Plant Breeding Station (SPBS, founded at East Craigs, Edinburgh, in 1921). In 1987, the Institute assumed managerial responsibility for Biomathematics & Statistics Scotland (BioSS), formerly the Scottish Agricultural Statistics Service.

Science

- Be an internationally recognised centre of excellence in plant and crop bioscience and products.
- Establish partnerships in key strategic research areas that are fundamental to the long-term vision for the Institute, which will include developing our links with universities and other related bodies.

Knowledge and Technology Transfer & Exploitation

- Be an internationally successful model for knowledge transfer and for the spin-out and exploitation of scientific research at the Institute.

Finance and Physical Resources

- Develop new funding and commercialisation relationships facilitated by an effective and responsive system of financial control.
- Provide a scientific, administrative and physical infrastructure that enables and supports high-quality, innovative, basic, strategic, and applied research.

Impact and Image

- Raise our profile and promote public awareness and understanding of relevant bioscience and environmental issues to assist informed public debate.

Human Resources

- Promote the recruitment and development of staff to the highest international standards to deliver the strategic science and commercialisation programmes.

Table 1. SCRI Strategic Objectives

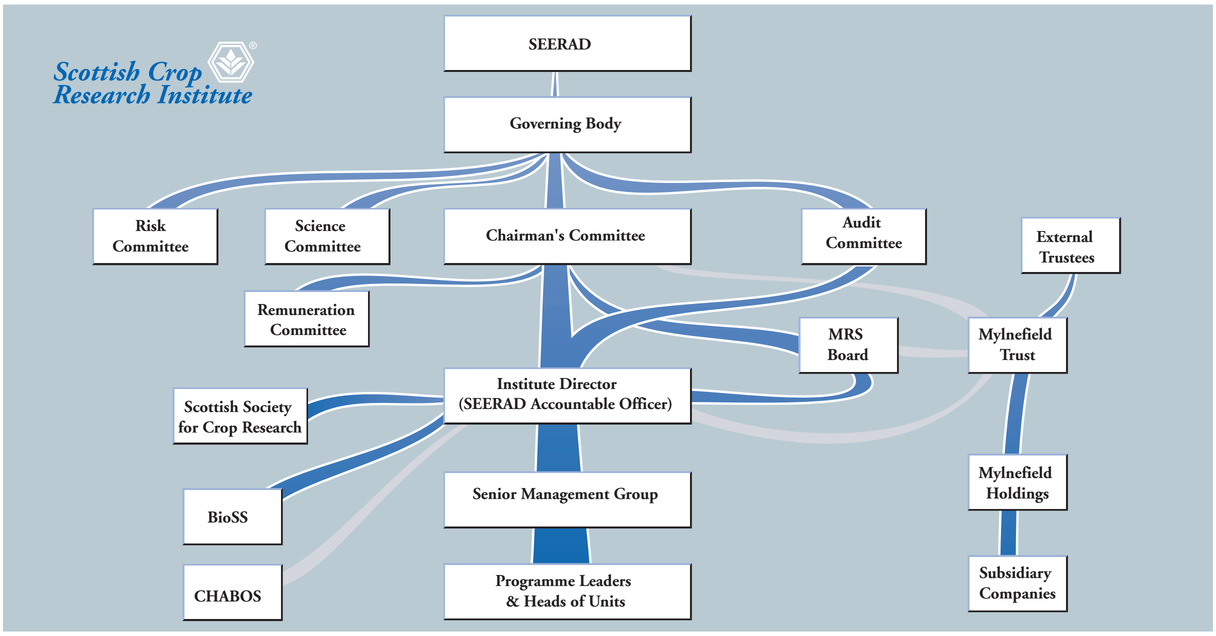

Figure 1 SCRI company and committee structure.

SCRI is a major international centre for basic, strategic, and applied research on agricultural, horticultural, and industrial crops and on the underlying biological processes common to all plants. It is the only such institute in Scotland and Northern Britain, and the range of complementary skills assembled at the Institute, from fundamental molecular genetics to glasshouse- and field-trials, with exploitation of the SCRI-based international genetic resources in a region of high phytosanitary conditions, is unique within the UK.

The science is optimised by a matrix-management system comprising three Themes and nine inter-related research Programmes. Management structures are regularly reviewed to ensure maximum effectiveness of the research at SCRI.

The SCRI research programmes are peer-reviewed at many levels. Each year, the 'core' programme of research comprising a number of projects is assessed by the Agricultural and Biological Research Group of SEERAD. All new projects are appraised by advisers prior to commissioning, the progress of the research projects is reported annually and, ultimately, final reports are produced for evaluation.

Every four years, SEERAD commissions the appointment of a Visiting Group to review the work of the Institute. The next Visiting Group is due May 2003 and in preparation for that visit documentation covering Quality of Science, Knowledge Transfer and Exploitation, and End Use Relevance has been submitted to three Assessment Panels. The Institute looks forward to the Visiting Group exercise and the opportunity to demonstrate the exciting research work undertaken at SCRI.

A broad multidisciplinary approach to fundamental and strategic research, and technology transfer, are special strengths of SCRI. Our programmes span the disciplines of genetics and breeding, molecular and cellular biology, biotechnology, plant pathology (bacteriology, entomology, mycology, nematology, and virology), plant physiology and cell biology, environmental science, plant chemistry and biochemistry, agronomy, molecular ecology, vegetation dynamics, bioremediation, serology, physics, mathematics, bioinformatics, and statistics. Genetics and enhanced breeding of selected crops, and biotechnology, lie at the core of all our substantial research, development, and training programmes.

The breadth and depth of knowledge, technical expertise, and infrastructural resources available at SCRI attract extensive contracts and consultancies from, and foster collaborations with, numerous academic and corporate organisations around the world. Memoranda of Understanding have been signed with a number of universities and organizations locally and overseas. Synergistic liaisons with other institutes, universities, and colleges in the UK and overseas are also integral to the scientific

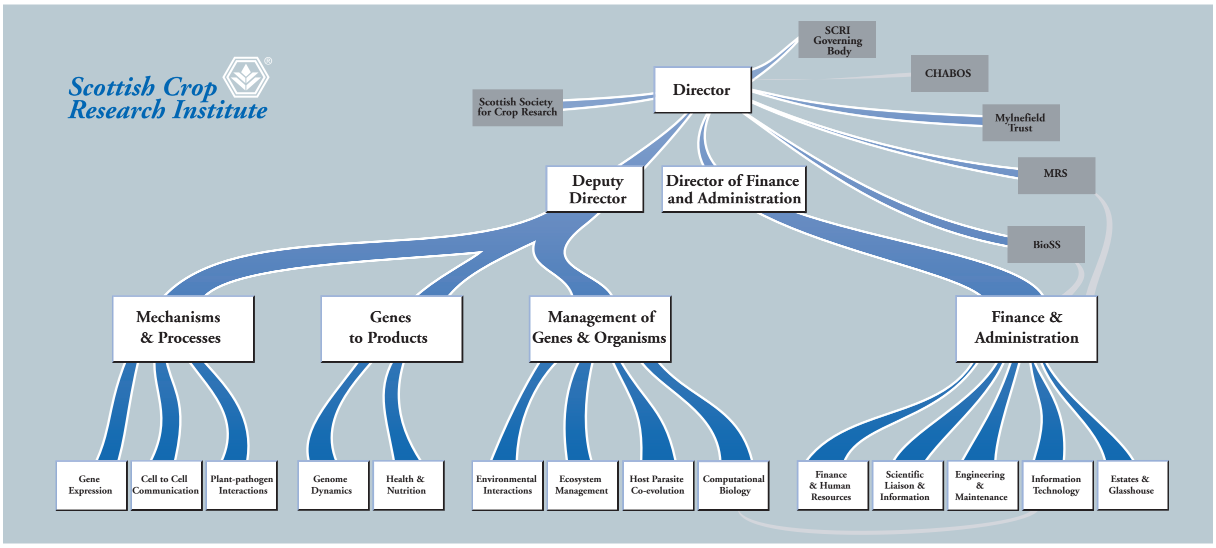

Figure 2 Institute management structure.

growth, development, and validation of the Institute's research activities. New links are being forged continuously, as well as existing contacts being developed and strengthened.

SCRI and Mylnefield Research Services (MRS) Ltd, the commercial arm of the Institute, are successful in gaining competitive research contracts from government departments and agencies, statutory Levy Boards, grower organisations, international agencies, the European Union, commercial companies, local government, and some Charities, Research Councils, and Trust funds, although we are largely excluded from submitting applications to the latter three sources. In February 2000, the Mylnefield Trust was registered; the Trust will support scientific research at SCRI by making gifts, grants, loans, or payments to the Institute subject to meeting its objectives. Also in February 2000, Mylnefield Holdings Ltd was established. Mylnefield Holdings Ltd is legally separate from SCRI and MRS Ltd but will obtain licences to SCRI technology and other necessary third-party technology that will enable it to establish spin-out companies. The new company will transfer money to SCRI and MRS Ltd through royalty and/or milestone payments.

In the two years to 31 March 2003, the Institute has spent over £5 million on capital equipment, which has allowed it to upgrade its glasshouses, controlled environment, and laboratory facilities, and invest in sophisticated analytical equipment. This, along with further funding to replace another glasshouse in 2004, has enhanced the Institute's ability to bid for competitive funding, has raised its international competitiveness, and has enabled the development of additional research programmes. The Institute is also continuing to develop proposals for the possible setting up of a Science Park at its Mylnefield site. The Institute is undertaking discussions with the relevant parties but will require the consent of SEERAD prior to any agreements being concluded.

The Institute has also invested in quality management systems, receiving accreditation under the ISO9001:2000 standard in October 2002, and has initiated an Institute-wide information and document management system, including a comprehensive upgrade of the Institute's intranet and web site, for implementation by August 2003. In addition, Mylnefield Research Services Limited (MRS) is now operating to Good Laboratory Practice Standard (an international standard) in the Lipid Unit. Staff have also received several awards including the Jones Bateman Cup awarded to R. M. Brennan for achievements in fruit breeding and the Scottish Horticultural Medal awarded to J. R. Hillman for services to horticultural science. K. J. Oparka was also promoted to Individual Merit Promotion Band 2 in July 2002. SCRI is accredited under the Investors in People scheme.

SCRI provides the base and secretariat for The Scottish Society for Crop Research (SSCR), a registered Friendly Society formed in 1981 by the amalgamation of The Scottish Society for Research in Plant Breeding and The Scottish Horticultural Research Association.

The SSCR provides an important link between SCRI research scientists and farmers, growers, processors, and other interested companies in the private sector.

The Society:

- organises interactive field walks and end-user/researcher discussion sessions;
- finances science-based advisory publications for the benefit of its members;
- stimulates crop-based sub-committees to support targeted research projects;
- reinforces SCRI representation with trade associations, Levy Boards, and other user-groups;
- administers the biennial Peter Massalski Prize to the most promising young scientist at SCRI.

SCRI is one of five Scottish Agricultural and Biological Research Institutes (SABRIs: Scottish Crop Research Institute; Hannah Research Institute; Macaulay Land Use Research Institute; Moredun Research Institute; Rowett Research Institute); and together with the Royal Botanic Garden, Edinburgh; the Scottish Agricultural College (SAC); the Scottish Agricultural Science Agency (SASA); the Fisheries Research Services; and Forestry Commission Research Agency, comprise the Committee of Heads of Agricultural and Biological Organisations in Scotland (CHABOS).

BioSS was established to cover the biomathematical and statistical needs of the five SABRIs and SAC. High-level consultancy, training, and research inputs from BioSS give a major advantage to the SABRI and SAC research programmes, as well as to the work of SASA and several other bodies for whom it carries out contracts.

This Report details a selection of the recent research achievements of SCRI, BioSS, and MRS Ltd, briefly describes the commercial rôles and successes of MRS Ltd, and summarises the important linking rôle of SSCR. Significant advances continue to be made in both fundamental and strategic science, with contributions to the protection and understanding of the environment. SCRI contributes to the debate on genetically modified crops, providing independent and unbiased information on this important subject. Discoveries are reported of direct and indirect benefit to agriculture, horticulture, forestry, land management, and biotechnology. Dedicated and talented scientific and support staff in the Institute, BioSS, and MRS Ltd, account for our stature, successes, and delivery of achievements.

Details of the annual accounts, Corporate Plan, health and safety provisions, and the SCRI/MRS quality-assurance arrangements are available on request.

On behalf of the staff and Governing Body, it is a pleasure once again for me to acknowledge with gratitude the staff of SEERAD for their continuing support of, and demonstrable commitment to, our research programme and to our development. Grants, contracts, donations, advice, and joint participation in our activities from the SSCR, other government departments and their agencies, non-governmental agencies, our sister CHABOS institutions, and BBSRC institutes with whom we coordinate our research, grower levy boards, local and regional authorities, commercial companies, farmers and other individuals, and learned societies, are also warmly appreciated. The Institute continues to remain buoyant in generally difficult times for science and agriculture in the UK, justifying its existence in every respect. We are confident that we shall continue to develop and thrive.

Report of the Director

John R. Hillman

Global perspectives of factors influencing agricultural, biological, and environmental sciences, and their associated industries : 2002-2003*

Preamble

Setbacks and Progress National security concerns, bankruptcies, commercial wrongdoings, a hiatus in business decision-making, and stock-market downgrades characterised the financial year 2002-2003 for the western economies, echoing the uncertainties created by the September 11th 2001 ('9-11') terrorist events. By mid-2003, however, there were signs of a strengthening of the global economy. Every day, 34,000 young children died from malnutrition and disease. Illegal immigration became politically high profile. More than five million terabytes of data were created in 2002, a prodigious amount of information, much of which was instantly forgettable, but the remainder a record of advancement in science, engineering, and technology to add to the achievements and intellectual advancements of mankind. Data production in 2003 will dwarf that of 2002.

"When you are courting a nice girl," said Albert Einstein,the Nobel laureate physicist whose bust sits on the windowsill of my Personal Assistant, "an hour seems like a second. When you sit on a red-hot cinder, a second seems like an hour. That's relativity." Agriculture is relatively more important than most other human activities – it is the basis of sustenance and civilisation, after all – but in terms of perception of those that people our towns and cities and body politic, it seems less important than entertainment, celebrity, sport, recreation, having a good time, and just about any other activity. That's relativity, too.

Terrorism In the political and economic aftermath of September 11th 2001, the USA declared a war on terrorism which began with the military attack on Afghanistan to rid it of the Al-Qaeda and the Taliban, and pressure worldwide was put on terrorist groups and their sponsors and supporters, especially those linked to Al-Qaeda, an organisation of extreme religious intolerance thought to be embedded in up to 60 countries. US President G. W. Bush in his State of the Union address in January 2002, identified Iran, Iraq, and North Korea as an 'axis of evil'. In May 2002, the US Administration named Cuba, Iran, Iraq, Libya, North Korea, Syria, and Sudan as sponsors, supporters or acquiescent of terrorism. Weapons of mass destruction, *i.e.* chemical, biological, and nuclear weapons, were a particular issue in US foreign policy, one shared by several western democracies. In June 2002, US President G. W. Bush stated that the out-

* This review updates and enlarges on themes developed in my previous accounts in the *SCRI Annual Report* series.

dated Cold-War policies of containment and deterrence should be replaced by a policy of pre-emptive strikes.

Conflation of terrorism with the effect of globalisation, post-colonial societies, urbanisation, economic deprivation and inequality, ready access to technical information, and Islam was to be expected following the 9-11 events. Cultural anthropology sought to dissect and interpret modern expressions of violence and their likely consequences, such as nationalism, isolationism, racism, religious strife, peacemaking, and reinforcement of cultural identities.

Anti-Americanism Anti-Americanism is, according to the French philosopher and author Bernard-Henri Lévy, one of the greatest sicknesses of the modern world. A survey of 16,000 people conducted by the Pew Global Attitudes Project noted a sharp decline in the international reputation of the USA and also of the United Nations (UN). Global attitudes to the USA, measured as a percentage favourable of the USA, grew more hostile during and immediately after the war with Iraq (20 March – 1 May 2003), but recovered somewhat by June 2003 when more than half of the people of seven countries were favourably disposed to the USA (Israel, UK, Kuwait – a nation recently invaded by Iraq, Canada, Nigeria, Australia, and Italy), but less than half of the populations of South Korea, Germany, France, Spain, Russia, Brazil, Morocco, Lebanon, Indonesia, Turkey, Pakistan, Jordan, and the Palestinian Authority were favourable disposed to the USA with the latter five having much less than a quarter supportive of the USA. With the exception of Nigeria, none of the countries surveyed showed the same level of support as in 1999-2000. Of those with an unfavourable opinion of the USA, the main reason cited was to do with President G. W. Bush, except in Israel, the Palestinian Authority, and South Korea, where the US in general was cited. Disenchantment with the USA by EU countries was reciprocated by US disenchantment with certain 'old Europe' countries that failed to support the USA-UK coalition in Iraq. European sensitivity over unilateralist US actions was no doubt heightened by a variety of factors such as a tangible anti-Americanism founded on Communist-influenced political tendencies, social statism, US multinational companies, jealousies over the international democratic and defence capabilities of the USA, an overt pro-Israel diplomatic stance by the USA, and its imposing economic and cultural dynamic. The Pew Project noted significantly that "the bottom has fallen out of support for America in most of the Muslim world". It also noted a softening more generally of support for the war on terrorism and commented on the weakening global public support for the two pillars of the post-World War II era, the UN and the North Atlantic Treaty Organisation (NATO). In parallel with the findings on the USA, the UN was seen to be increasingly irrelevant by more than 40% of those surveyed in 21 countries; and 60% or more believed this to be the case in Brazil, France, Israel, Jordan, Lebanon, Pakistan, the Palestinian Authority, South Korea, and the USA.

Social Protection Rising costs and complexities of social security or social protection programmes in most of the more-developed countries (MDCs) led to revisions of the degree of protection, often under the guise of offering a greater range of options. Budgetary constraints led the imposition of a raft of measures including time limits and work requirements for welfare recipients; means testing; taxation incentives; encouragement of marriage and enforced child maintenance payments by parents; training; private-sector medical insurance; controls over the costs of prescription drugs, and medical, dental and eye care; encouragement of faith-based support; increase in retirement age; compulsory retirement pension payments; tightening eligibility criteria for disability pensions; compulsory employer support for outplacement services; enhanced employee rights in respect of health and safety measures, training, hours worked, and protection from dismissal; and vouchers for food, clothing, shelter, and household goods. Eligibility for social protection was an issue in some countries sensitised by debates over immigration, illegal aliens, refugees, and asylum seekers, which together with efforts to combat terrorism, heightened the level of debate over compulsory national identity cards and sophisticated surveillance measures which could extend to the workplace. In the UK, of the £456 billion total Government spending, social protection accounted for £133 billion – the largest slice; followed by the National Health Service at £72 billion (other health and personal social services cost an additional £17 billion); education £59 billion; law and protective services £27 billion; defence £26 billion; debt interest £22 billion; housing and the environment £20 billion; and industry, agriculture, and employment £16 billion. Other spending amounted to £49 billion.

Peer Review Peer assessment of scientific research was called into question in September 2002 when J. H. Schön was dismissed by Bell Laboratories, New Jersey, USA, following accusations that he falsified data in scientific papers on nanotechnology published from 1998 to 2001 in high-impact refereed journals. Coverage of science-related issues in the publishing and broadcast media has been unduly influenced by lurid stories and scaremongering on such matters as human cloning, nanotechnology, the MMR (mumps, measles and rubella) vaccine, genetically modified (GM) crops and foods, climate change, species extinction *etc*., without the claims having been subjected to rigorous review by independent scientific experts in the relevant area of study *i.e.* 'peers'. A noteworthy example of flawed science being reported worldwide before peer review was the research reported by A. Pusztai on GM potatoes. From time to time, it is to be expected that a limited amount of inadequate or fallacious work will slip through the reviewing system as a result of overworked referees and editors, usually acting voluntarily, trying to operate within tight deadlines. Criticism of the use of anonymous referees on the basis of either 'if they are independent and knowledgeable, why should they wish to remain anonymous?' or 'are the scientific or political establishments wishing to retain the ability to suppress unorthodoxy?' has been stated for many years, but it is generally recognised that the system is infinitely better than a low- or no-standard free-for-all. My view is that the reviewing system should be transparent and that anonymity is no longer justified. Yet, underlying the debate are the intrinsic integrity and objectivity of the scientist(s) (for without these assets science is doomed) and the ability of other scientists to check and take forward the observations, discoveries, concepts, conclusions, and products. Peer review is used as a self-regulating quality-control mechanism, and is regarded as a part of a system that ensures the published literature is as accurate and balanced as possible, in so doing providing constructive advice and observations on raising the standards of the submitted work. It is also used to apportion research funding. There are dangers in creating citation and grant-awarding cartels, bandwagons, and an attitude that fails to appreciate that not all science is or should be hypothesis-driven; there is a substantial need for curiosity-led exploration and inadvertent discovery, activities that the conventional peer-review system tends to downplay, as it does to applied research.

Genomes Determination in 2001 of the complete DNA sequence of the human genome was a prime driver in sequencing the genomes of other organisms, including pests and diseases, and developing the tools and concepts needed to understand gene function and regulation. In 2002, the physical map and draft sequence of the 2,800 million base mouse genome was published, sharing a remarkably high degree of conserved synteny between mouse and human. Also in 2002, the full genome DNA sequence was published for the protozoan parasite responsible for the most severe form of human malaria, *Plasmodium falciparum*, as well as for the rodent-infecting *P. yoelii yoelii,* and for the malaria vector, *Anopheles gambiae*. Other organisms sequenced in full during 2002 included the 160 million base sea squirt *Ciona intestalis*. One of the six chromosomes of the motile slime mould, *Dictyostelium discoideum*, was also sequenced. In 2003, the draft genome sequence for the 42.9 million base bread mould, *Neurospora crassa*, was published; as a result of repeat-induced point mutation removing duplicated sequences, there is little redundancy in its genome. In the same year, it was possible to compare the completed genome sequence of *Bacillus anthracis*, the cause of anthrax, with other important Bacilli. Although virulence factors in the Bacilli have been localised to genes on their plasmids, *B. anthracis* is distinct from its close relatives by the existence of a pathenogenicity island on one of its two plasmids, pXO1, as well as for genes for several of the virulence factors carried on the chromosome.

RNAi RNA interference (RNAi) as a mechanism for gene regulation is of special interest in the research programme of SCRI, as well as research elsewhere on diagnostics and therapeutics. It would appear from studies on eukaryotic organisms that the components of the mechanism are highly conserved between species and organisational groups. In essence, genes can be silenced by double-stranded RNA (dsRNA) versions of their coding sequence, beginning with pairs of the protein molecule Dicer binding to dsRNA, cutting it into 22-nucleotide-long small interfering RNA molecules (siRNA), which are then delivered to the RNA-induced silencing protein complex RISC which in turn contains nucleases, enzymes that cleave RNA. Approaches to investigate and utilise the RNAi machinery in knockout analyses and silencing were best illustrated in the work on the nematode *Caenorhabditis elegans*, a famous model system for developmental biology. By use of specially constructed plasmid clones, inducibly producing dsRNA for 16,757 of the organism's 19,427 predicted open reading frames, RNAi silencing effects were noted on genes that are highly conserved in eukaryotes, and tend to be clustered in regions of up to 1 million bases long.

Plants Plant scientists found much of relevance in the research on animal stem cells, cells akin to plant meristematic cells that can both replicate indefinitely or give rise to a range of differentiated cells. Some stem cells have a degree of pre-determination and are committed to produce specific tissue types. Much of the public and political debate over human stem cells concentrated on the use of foetal cells and was tied into issues of abortion and human cloning. Stem cells derived from adult tissues that show varying degrees of totipotency attracted a great deal of research, ethical, and applied medical interest. In plants, the control systems underpinning meristematic activity, differentiation, de-differentiation, as well as cellular, organismal, and population senescence, are now capable of being unravelled by molecular genetics combined with proteomics, metabolomics, and bioinformatics.

Evolution A fascinating development in the understanding of the origins and evolution of cellular organelles in eukaryotes came with investigations on the binary division of mitochondria and chloroplasts. It is known that in prokaryotic cells, the functioning of the contractile protein that causes the pinching and binary fission of the cells (FtsZ), is dependent on the hydrolysis of the nucleotide guanosine triphosphate (GTP). FtsZ-dependent division also occurs in the chloroplasts of green higher plants and algal mitochondria. In contrast, yeast and nematode mitochondria use another protein belonging to the dynamins group of proteins which also draw on GTP hydrolysis. It was proposed that an evolutionary transitionary development of mitochondria took place in which both FtsZ and the dynamin-related protein functioned together, one on the inner surface of the inner membrane surrounding the organelle, and one on the outer surface of the inner membrane. Prospects for discovering of such a transition phase were enhanced by the fact that FtsZ has been found to form a constricting ring on the inner surface of the inner membrane of gram-negative bacteria, the chloroplasts of green plants, and the mitochondria of red algae; the dynamin-related protein has been found on the outer surface of the inner membrane in higher-plant mitochondria.

The year 2002-2003 was one when a new conifer species forming a new genus, *Xanthocyparis*, was discovered, as well as a 125-million-year-old fossil of *Archaefructus sinensis,* giving rise to the view that the ancestors of the angiosperms may have been aquatic weedy rather than highly lignified woody plants similar to the magnolias. The commonly held concept of low-biodiversity tropical rainforests in the Paleocene was reconsidered after the discovery of a diverse fossil leaf site was dated to a period only 1.4 million years younger than the Cretaceous-Tertiary extinction event 65 million years ago. To put this into context, earth is thought to have come into existence about 4,600 million years ago, but was thought to have been uninhabited for the first half of this period – the Archean Era or Eon. Life was generally believed to have emerged in the succeeding Proterozoic Era. Often, the Archaen and Proterozoic Eras are referred to as the Precambian. There was structural evidence from studies on single-celled eukaryotic algal fossils from the Roper Group rocks in Australia, that the eukaryotic life-form must have evolved between 2.5 billion and 2.7 billion years ago in the late Archean Eon. The Precambian Era gave way to the Palaezoic ('ancient life; circa 550-248 million years ago; comprising (oldest to youngest) the Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian Periods), followed by the Mesozoic Era (middle forms of life; circa 245-65 million years ago; comprising the Triassic, Jurassic, and Cretaceous Periods), followed by the Cenozoic Era ('recent life'; from *circa* 65 million years ago; comprising the Paleocene, Eocene, Oligocene, Miocene, and Pliocene Epochs of the Tertiary Period, and the more recent Pleistocene and Holocene Epochs of the Quaternary Period). To accompany the evolutionary considerations, I recommend the excellent paper *A revised six-Kingdom system of life* by T. Cavalier-Smith. *Biol. Rev.* **73**, 203-266, 1998.

Satellites Whilst there was scientific debate about the planetary nature of the larger trans-Neptunian objects, not least the body provisionally named Quaoar (2002 LM60) that is beyond the orbits of Neptune and Pluto, the costs and value of manned spaceflight were re-evaluated following the destruction of the shuttle orbiter *Columbia* in February 2003, as it was descending to Cape Canaveral, USA. The previous year, assembly of the International Space Station was the primary focus of manned missions, although one successful operation was carried out to service the Hubble Space Telescope. Agriculture was an interested party in the launching and operation of unmanned satellites to detect environmental changes on earth. Monitoring of sea-level changes, ice melting, ice caps, the global water cycle, the ozone hole, desertification, cloud formation, vegetation cover and agricultural land management, floods and sandstorms, pollution events *etc.* became an essential tool for all types of land management, as well as for predicting weather systems, oceanic changes, and the impacts of climate change.

Libraries Libraries as repositories and vehicles for scholarship were influenced by both positive and negative forces during 2002-2003. An array of information technologies to acquire, analyse, and disseminate knowledge came on stream, Internet connections aided library consortia to be formed, and library facilities were upgraded to become computer-friendly. Major new libraries were under construction in Montreal, Canada, and New Delhi, India. Most libraries were subject to budgetary constraints, however, and some were damaged by natural disasters (*e.g.* flooding damage to the Prague Municipal Library), and by human mistakes (*e.g.* damage from a sprinkler system in the National Library of Canada). In the USA, confidentiality of library records was compromised by the acquisition of powers to monitor for terrorism or activities that damage national security. The interface between scientific research and libraries was starting to be reviewed in the context of the rapid development of bioinformatics, Web-based journals, an era of multi-authored publications, attitudes (sadly) that do not favour non-illustrated text, and the need for interactive assistance in constructing publications and databases.

Media Science and technology items were not foremost in the outputs of the broadcast and publishing media in 2002-2003 and rarely attracted large audiences or readerships, even though science and technology are the basis for the functioning of the massive modern media and publishing industries. Celebrities, talk shows, game shows, professional sport, comedy, drama series, "soap operas", reality-TV shows, popular music shows, and news-related shows that incorporated much of the foregoing as well as conventional news, dominated screens and radio broadcasts. Satellite broadcasting reaching across national borders continued to expand, aided by news programmes that responded quickly to major events such as acts of terrorism, natural disasters, and warfare, as well as frivolous happenings in the lives of celebrities. Programme content was of special interest to educationalists, sociologists, government, advertisers, pressure groups, regulators, politicians, watchdogs, psychologists, psychiatrists, and those hounded by the media. Freedom of expression in the media as defined in western democracies was restricted in several countries such as China, Cuba, North Korea, and various Arab countries, restrictions that became increasingly difficult to impose, and an anathema to scientists.

The newspaper industry was forced to restructure somewhat during 2002 as the recession in advertising and competition from free commuter newspapers, other forms of publishing media, broadcasting, and the Internet took hold. Redundancies and reshaped presentations (content and design) were the principle routes to maintain profitability. Routine reporting of agricultural and horticultural matters continued to decline. Classified employment advertising and local-retailing advertising remained weak, and were particularly vulnerable to Internet developments. Despite these difficulties, the decline in the circulations of newspapers in MDCs was only around 1%, but circulation penetration – copies sold to the general public rather than the estimating readership as a whole – declined more sharply. Surveys indicated that younger people resorted to digital options for information and news, a finding which has led the newspaper industry to create newspaper-linked Web sites. One of the most interactive forms of communication between reader, viewer, and journalist was the rapid development of Web logs ('blogs') to the point that by mid-2002 there were about 500,000 blogs, aided by the availability of free blog-creation software.

Book sales rose by about 3% in 2002, mainly on the back of paperbacks and Spanish-language books. Open e-Book Forum pointed to a 10%-15% increase in sales, and an even greater increase in the downloading of e-book readers.

Intellectual property issues were central to book publishing. In March 2002, the digital copyright treaty formulated by the World Intellectual Property Organisation, came into force, supplementing the Berne Convention for the Protection of Literary and Artistic Works, as revised in 1971. Within the EU, member states grappled hesitantly with the application of value-added tax (VAT) to imported digital products such as e-books, the abolition of resale price maintenance, payments relating to public lending rights, the rate of VAT applied to books, and the legal relationship between authors and publishers.

EU Research G. Schatz in *Jeff's View. Networks, Fretworks,* FEBS Letters 553, 1-2, 2003, amusingly pointed out the deficiencies of the European Research Area, and the inability of the EU to replace the USA and become the world's most competitive and dynamic knowledge-based economy. Despite matching the USA in scientific output, the EU is inferior in generating innovation. Europe suffers from serious misconceptions about how science functions, the degree to which it can be planned and regulated, and the way in which coordination, cooperation, and evaluation override scientific leadership. This is illustrated by enforced networks, micromanagement to provide accountability and avoid risk, phenomenal levels of bureaucracy, and the absence of leading scientists from shaping EU research policies. Dr Schatz cited Lord Ernest Rutherford's dictum "It is essential for men of science to take an interest in the administration of their own affairs or else the professional civil servant will step in – and then the Lord help you".

AIDS Agriculturally dependent economies of the less-developed countries (LDCs; countries defined by the World Bank in *World Development Report 2003* as having a gross national product in 2001 of less than $9,205 *per capita*) have been severely affected by the acquired immune deficiency syndrome (AIDS) pandemic. By 2002, over 40 million people worldwide were infected by the disease, and new infections were reported to be 15,000 *per* day. In sub-Saharan Africa, more than 20% of adults were infected with human immunodeficiency virus (HIV), and average life expectancy was less than 40 years. The US National Intelligence Council reported that by 2010, there would be between 50 million to 75 million AIDS cases in China, Ethiopia, India, Nigeria, and Russia. Guidelines were issued by the World Health Organisation (WHO) for minimal acceptable laboratory tests for diagnosing HIV infection and monitoring treatment regimes. Discussions took place with major pharmaceutical companies on the release of intellectual property and drug cocktails to treat patients in LDCs, with agreement between the parties reached by early 2003.

SARS Outbreaks of severe acute respiratory syndrome (SARS) in early 2003, a disease thought to have originated in southern China, raised questions about the emergence of new infectious agents, methods of control and detection, and the roles of long-distance travel, population growth, and genetic variability in both the host and agent. SARS spread to 29 countries, infected more than 8,000 people, killed 774 people, and was responsible for a partial collapse of the global tourism and business travel industry. The global cost was calculated by economists from the Australian National University at between £22 billion and £80 billion.

Diets In food-secure countries, the incidence of cardiovascular disease, diabetes, and obesity provided a fresh impetus to understand and optimise diets. Fast-food chains were beginning to attract litigation and industries associated with the production and retailing of starch-based foods were adversely affected by the impact of the Atkins Diet. The composition of foodstuffs and concepts of 'healthy' diets were being re-investigated in the light of discoveries about variations in the human genome, leading to the concept and area of study referred to as nutrigenomics. Plant genome - human genome interactions are now a viable area of study, aided both by transgenic technology to modify precisely plant compositions, and by more sophisticated understanding of pharmacogenomics. Several groups raised ethical questions about access to individual's genetic data, types of market testing, and global access to knowledge, activities that perhaps should remain confidential. The WHO recommended governments to consider using taxes to dissuade people from eating too much sugar, fats, and salt in order to curtail the impacts of poor diets on obesity.

Education Standardised achievement tests to judge the proficiency of schoolchildren were a common feature of many of the MDCs in 2002. Such tests were criticised as ponderous, costly, and likely to lead to the neglect of non-examined but essential parts of the curriculum. Centrally set performance indicators for schools and teachers were beginning to be introduced. Other issues included relatively poor pay for teachers, the educational background and competencies of teachers, drug-testing of pupils, discipline, truancy, and the relationship between government and religious education. Western governments sought to drive educational change in certain Islamic countries that suppressed the education of girls or promoted anti-Western attitudes in the young.

Higher education attained a political profile that befits its societal importance, challenging those that fund these custodians of scholarship and the knowledge economy. As the full economic recurrent and capital costs of state-owned or state-financed largely charitable institutions were debated, profit-making institutions were beginning to gain greater prominence and course-based, student charges were reassessed. Governments of both LDCs and MDCs tended to regard universities and colleges as training establishments to foster entrepreneurialism, wealth creation, and innovation, thereby emphasising often unwittingly an expensive research and development role too. The quality of education and the type of courses provided were questioned centrally in countries as diverse as China, France, Germany, Russia, and the UK. Arab institutions came under scrutiny in order to address the need to revitalise the socio-economic conditions of many of the Arab nations. Distance learning, usually involving the Internet, in-class teaching, and hybrid instruction (Internet plus in-class teaching) served to widen the student base. Science and technology education in many of the MDCs, especially the EU, were under stress given the high costs of instrumentation, technical support, and consumables, as well as associated health and safety costs in litigious societies. In the UK, the structural and financial relationships between the state-sector-controlled universities, the Research Councils, government departments, various research-supporting charities, and the government-sponsored research institutes were subject to several reviews, including assessments of the quality of science and corporate governance processes. There was general acceptance that the majority of the best universities in the world were a group of especially well-funded establishments in the USA.

According to I. McNicoll, U. Kelly, and D. McLellan, in *The Economic Impact of Scottish Higher Education*, 2003, the total income in 2001-2002 of the Scottish higher-education institutions (HEIs) was nearly £1.7 billion, 51% of which was core public-sector funding, 16% competitively awarded public expenditure, 23% from the private sector, and 10% from overseas. Employing 36,800 full-time-equivalent (FTE) staff, the HEIs generate nearly 11,000 additional FTE jobs throughout the rest of the Scottish economy, accounting in total for 2.65% of total Scottish employment.

Civil Engineering Projects Major civil engineering projects completed in 2002-2003 included four dams and hydrological projects: (a) the longest was the San Rogue Multipurpose Dam on the Agno River Luzon, Philippines, and is the tallest earth-and-rock-fill dam in Asia; (b) the Mohale Dam on the Senqunyane River, Lesotho; (c) the Alqueva Dam on the Guadiana River, Portugal, which creates Europe's largest reservoir of *circa* 250 sq. km; and (d) the 36 sq. km Davis (holding) Pond near the Mississippi River, USA, representing the World's largest freshwater diversion project designed to replenish 31,000 sq. km of wetlands by controlled seasonal flooding.

Economics and Politics

Growth Global economic growth in 2002 was below trend, as equities, company values, and profits declined, and preparations were put in hand for a military confrontation between the USA and UK on the one hand and Iraq on the other. The International Monetary Fund (IMF) projected growth in 2002 of 2.8%. Even so, by October, global equities had fallen by 24% from the beginning of the year, and by 42% from the April 2000 peak. This dramatic decline represented the largest loss of wealth since World War II, as $14 trillion was lost in tandem with depressed profit forecasts and accountancy scandals and obfuscations.

Growth in the LDCs (4.2%) exceeded that of the MDCs (1.7%) where the USA provided the economic engine on the back of strong governmental spending (some refer to it as investment) and resilient personal (consumer) spending, resulting in increased debt. Demand was further enhanced by low interest rates, assumed perhaps rashly to persist for the foreseeable future. Inflationary pressures were subdued to the point that the possibility of deflation raised concerns in some economic reports.

As D. Smith, the economist and Sunday Times journalist stated, the story of the 21st century will surely be a marked shift of economic power to the east. D. Wilson and R. Purushothaman in *Dreaming with Brics: The Path to 2050*, Goldman Sachs, 2003, projected the economic evolution of Brazil, Russia, India, and China (Brics), the four fastest-growing emerging economies, based on a complex growth model. The gross domestic profit (GDP) of China is predicted to exceed that of France in 2004, the UK in 2005, Germany in 2007, Japan in 2016, and the USA in 2041. In 30 stable years, the economy of India may be only a third of that of China and the USA. Even so, on a *per capita* basis, by 2050, the performance of the Chinese and Indian economies would lag behind those of the Group of Seven Countries (G-7) economies. Nations of static or declining populations (much of Europe for example) will need to reconfigure their economic structure to focus on wealth-creating activities of global impact. (see **Populations and Conflicts**)

Corporate Governance Strengthened corporate governance arrangements in the MDCs were being introduced in the wake of an undermining of investor confidence by poor financial reporting, corporate leadership that abused its integrity, and sheer deceit to the point of beggaring belief. Triggered to some extent by the collapse of Enron Corporation in late 2001 - an energy-trading company deemed by professional investors and authorities to be highly successful and innovative - the conviction of its auditors, Arthur Andersen, unsettled accountancy companies worldwide leading to the formation of limited liability partnerships. Thereafter, various technology companies came under scrutiny for unjustifiably inflating profits *e.g.* WorldCom Inc., Xerox Corporation, and Vivendi Universal, adding to market volatility. In July 2002, the Sarbanes-Oxley Act was introduced in the USA, replacing self-regulation of the accountancy profession with a public body, reinforcing the independence of the audit process, and insisting on the release of timeous and accurate corporate information to the markets. (see also **Financial Reporting** and **Corporate Governance** in the **UK Perspectives** section)

China Political considerations added to the financial challenges faced by many LDCs, whereby flights of capital were generated by political upheavals. China, however, weathered the financial stresses experienced by most LDCs, as it progressed in converting to a capitalist culture and becoming a global superpower in terms of export of manufactured goods and expanding internal consumer markets.

FDI Foreign direct investment (FDI) fell in the MDCs as economic growth slowed, and mergers and acquisitions across national boundaries – one of the main vehicles of FDI - diminished. FDI of $621 billion in 2002 represented just 55% of the level recorded in 2000, the largest fall since the early 1970s. Multinational or transnational companies for the most part continued to expand, nonetheless, and the total number of their employees increased to 54 million. Coinciding with its membership of the WTO, China was the recipient of increasing levels of FDI. In fact, FDI into the LDCs declined only by 14% to $205 billion. In terms of overseas direct investment in stock which totalled $7,122.506 billion in 2002 according to the United Nations Conference on Trade and Development (UNCTAD) *World Investment Report 2003*, the major ten recipients in descending order were the USA, UK, Germany, China, Hong Kong (China), France, The Netherlands, Brazil, Canada, and Spain. The top ten global outward investors in stock in 2002 out of a total of £6,866.362 billion were the USA, UK, France, Germany, Hong Kong (China), The Netherlands, Japan, Switzerland, Canada, and Spain.

USA The economic performance of the USA was patchy in 2002, as it responded to the ending of 10 years of more or less continuous expansion. Recovery from a brief but mild recessionary period after the September 11 2001 attacks was remarkably brisk, especially in the light of the sharp fall in company profits, accounting irregularities, employment, and inventories. Deflation was not an issue, nor was serious inflation. Low interest rates and personal taxation cuts sustained high domestic spending which accounted for around 75% of gross domestic product (GDP). Imports met much of the strong domestic demand and increased by nearly 3.5% in volume terms whereas exports declined by 1%. Together with increased military and security spending, the drop in taxation revenues accounted for a reversal in the position of the public finances and a deficit of $159 billion was registered at the end of September 2002, equivalent to 1.5% of GDP, contrasting to the $313 billion surplus (3% of GDP) estimated in January 2002. A $550 US current-account deficit was predicted for 2003.

Japan The Japanese economy declined by 0.7%, continuing the deflationary environment established over the previous 18 months. Non-performing bank loans were conservatively estimated to be the equivalent of 8% of GDP, around $362 billion.

EU The euro-zone countries (Table 1) experienced mixed fortunes as the European Central Bank operated its 'one-size-fits-all' policy of keeping the overall inflation rate below 2.5%. The national governments of the zone had no mandated powers to control their economies under the Growth and Stability Pact. Consequently, highly variable inflation rates coupled to unaffordable wage and social spending demands placed strains on the euro-zone economy. According to the Bundesbank and Bank of France, the European single currency failed to boost trade between euro-

Member States	Accession States - Entry 2004	Countries for Possible Entry 2007	Aspirant Countries
Austria*	The Czech Republic	Bulgaria	Albania
Belgium*	Cyprus	Romania	Bosnia & Herzegovina
Denmark	Estonia		Croatia
Finland*	Hungary		Macedonia
France*	Latvia		Montenegro
Germany*	Lithuania		Serbia
Greece*	Malta		Turkey
The Republic of Ireland*	Poland		
Italy *	Slovakia		
Luxembourg*	Slovenia		
The Netherlands*			
Portugal*			
Spain*			
Sweden			
United Kingdom			

*=Euro-zone countries

Table 1. The European Union

zone members, as its largest economics sank into recession, and they became increasingly reliant on export markets in the UK, USA, and elsewhere.

The EU was estimated by the Organisation for Economic Co-operation and Development (OECD) and the *IMF World Economic Outlook* (September 2002) to have had a percentage annual change in GDP of 1.1%, compared with 1.7% in all MDCs, 1.4% in G-7 countries, 2.2% in the USA, 3.4% in Canada, 1.7% in the UK, and –0.5% in the deflationary climate of Japan. Interestingly, the countries in transition (former centrally planned economies) grew by 3.5% as economic reforms started to take hold, with virtually all the economic benefits confined to urban and suburban areas.

The development of the EU has been one of institutional upheaval. It developed from the European Coal and Steel Community (ECSC) that was formed in 1951 by Belgium, France, Germany, Italy, Luxembourg, and The Netherlands signing the Paris Treaty. By signing the 1957 Treaty of Rome, the six ECSC countries constituted the European Economic Community (EEC) and the European Atomic Energy Authority (EURATOM). This 1957 treaty created a customs union; common agricultural, fisheries, and external trade policies; and coordinated economic and social polices, as well as nuclear research and development. In 1962, the first version of the Common Agricultural Policy (CAP) was agreed. The European Communities (EC) was formed in 1967 from a merger of the ECSC, the EEC, and EURATOM, giving rise to a single Council of Ministers and European Commission. Denmark, the Republic of Ireland, and UK joined the EC in 1973. By 1974, the heads of governments began their routine summit meetings. It was in 1975 that the UK renegotiated its terms of accession to the EC, a period when the European Regional Development Fund was established. The European Monetary System (EMS) was established in 1979, the year when the first direct elections took place to the European Parliament. Greece joined the EC in 1981. Agriculture in the UK was affected during the 1980s with three developments: (a) in 1984, the Fontainebleu summit grudgingly agreed the UK annual budget rebate and equally reluctantly the first major CAP reform; (b) in 1986, the Single European Act (SEA) was signed in the year when Portugal and Spain joined the EC, and European Political Co-operation (EPC) established; (c) in 1988, there was the second major CAP reform. Parenthetically, the target date for the completion of the major elements of the SEA was 31 December 1992, prior to coming into effect on 1 January 1993; yet trade barriers persist and harmonisation of taxes, removal of frontier controls, recognition of professional qualifications, reduction of state aid to certain industries, open tendering *etc.* have yet to be achieved. The 1990s represented a further coming together of the member countries. In 1991, the Maastricht Treaty was agreed; the single internal market programme was completed at the end of 1992. Shortly after the Exchange Rate Mechanism (ERM) of the EMS was suspended in 1993, the Maastricht Treaty entered into force, establishing the European

Union (EU). At the beginning of 1994, the European Economic Area agreement came into force, and Norway rejected membership of the EU. In 1995, Austria, Finland, and Sweden joined the EU. The Amsterdam Treaty was agreed in 1997. In 1998, 11 EU Member States were chosen to enter the first round of the European Monetary Union (EMU), and the European Central Bank (ECB) replaced the European Monetary Institute. At the beginning of 1999, the euro (€) currency was launched, followed by agreement of the Agenda 2000 financial and policy reform to address enlargement of the EU, and then by the Amsterdam Treaty entering into force. The Treaty of Nice was agreed at the end of 2000, but was rejected by the Republic of Ireland in mid-2001. At the beginning of 2002, euro coins and banknotes entered circulation.

In my previous *Director's Report*, I described the enlargement processes and various aspects of the external relations of the EU. In its *modus operandi*, the Council of the EU (the so-called Council of Ministers) was formally comprised of the foreign ministers of the Member States, but functionally involves those ministers appropriate to the topic under discussion. The Treaty of Nice affected the size of the European Commission and voting mechanisms in the Council of Ministers. The European Council comprises the heads of government or state of the members, with the President of the European Commission. The presidency of the European Council is held in rotation for six months only. In 2002, the presidencies were held by Spain then Denmark, in 2003 by Greece then Italy; in 2004 the Republic of Ireland then The Netherlands will hold the presidencies. The invitation and implementation of EC legislation is through the European Commission, staffed by *circa* 16,000 permanent civil servants. Direct democratic control over the EU comes in part from the 626-seat European Parliament, a body that holds sessions in Brussels and Strasbourg; the Secretariat's headquarters are in Luxembourg. Through the Single European Act, the Maastricht Treaty, and the Amsterdam Treaty, the Parliament has extended powers and influence, as demonstrated by its sometimes robust approach to the appointment and forcing the resignation of the European Commission, modifying expenditure, and driving legislation.

Much interest is shown in the Community Budget, which in the *General Budget of the European Union for the Financial Year 2002* was given as €98.7 billion. This budget was in line with the Edinburgh summit agreement in 1992 in which the EU budget rose to a maximum of 1.27% of the EU's gross national product (GNP) in 1999, a ceiling agreed to operate up to 2006, but with resources devoted to existing Member States falling to accommodate enlargement of the EU.

As the CAP evolved, it assumed a major portion of the Community budget. In 2002, 44.9% of the budget was spent on agriculture, compared with 34.3% on regional and social spend, 4.9% on external action, 3.3% on pre-accession aid, 6.6% on internal policies, 5.3% on administration, and 0.7% on reserves. Spending commitments, however, have ballooned in recent years, and for nine consecutive years, the European Court of Auditors has refused to validate the EU accounts, finding material errors in the agriculture spend, as well as lax controls and poor supervision by Member States in the spending of the structural funds. Through a combination of measures such as export subsidies, intervention purchases, and import levies, the original aim of the CAP was to increase agricultural production, offer a reasonable standard of living for farmers and thereby support the rural economy, and equally important, ensure the availability of food at relatively low prices. As a result, production was stimulated but the CAP budget ballooned as the Community enlarged, and output increased as new yield-enhancing technologies (new cultivars, automation, and agrochemicals) were introduced. Five major reforms to the original CAP have been carried out. In 1984, the system of co-responsibility levies was launched, reinforced by national quotas for specific commodities, such as milk. 'Set-aside' arrangements to remove land out of production in order to curtail politically embarrassing surpluses were introduced in 1988. In 1993, the complex set-aside arrangements were extended for a further five years and were applied throughout the EU. In 1999, cuts took place in intervention prices in order to reduce surpluses of beef, cereals, and milk; in compensation, area payments were paid to producers. There was also the intention of simplifying CAP rules. During the period January 1995 to January 2001, the EU should have met its obligation under the Uruguay round agreement of the General Agreement on Tariffs and Trade (the progenitor of the World Trade Organisation - WTO which was established in January 1995), by reducing its import levies by 36%, reducing its domestic subsidies by 20%, reducing export subsidies by 36% in value and reducing subsidised exports by 21% in volume. A peace clause, agreed during the Uruguay round, sheltered EU and

US subsidies from legal challenges but was due to expire at the end of 2003, leaving open the possibility of disputes requiring resolution by the WTO panels. Agenda 2000 is scheduled to increase the cost of the CAP by a billion euros in the lead in up to integration of the accession countries into the EU, eventually stabilising by the end of 2006. Negotiations on the Mid-Term Review of the CAP during 2002 and 2003 were directed towards further reducing the impact of the CAP on market-unrelated production.

Continual transformation of the EU was predicated by the signing of the Maastricht, Amsterdam, and Nice Treaties, leading to a prolonged series of institutional, social, and economic reforms. Economic and monetary union (EMU) was set in train by the Maastricht Treaty, as well as such matters as the defence role of the Western European Union, co-operation on home and justice affairs, increased powers for the European Parliament, a common citizenship, qualified majority voting in the Council of Ministers in some areas, the principle of subsidiarity (largely ignored), and extension of centralised competency into consumer affairs, health, education, training, as well as environmental and industrial policies. By 2003, Belgium, France, Germany, and Luxembourg had failed to implement more than 200 European Directives into national law. Besides extending the scope of qualified majority voting, the Amsterdam Treaty was noted for the formal commitment to human rights. The Treaty of Nice also extended the scope of qualified majority voting, but was especially noted for its facilitation of the eventual accommodation of up to 13 new members of the EU. Interestingly, only the Republic of Ireland permitted its population to vote in a referendum on the Treaty; 54% of voters rejected it. As 12 EU countries constituting the euro-zone rapidly and smoothly accommodated to the introduction of the common currency introduced at the beginning of 2002, European integrationists pressed ahead with modifying the EU institutions and decision-making processes to ensure the EU could function with a greatly enlarged membership. Modelled on the 1787 Constitutional Convention of the USA and arising from the Laeken Summit in December 2001, the Convention on the Future of Europe was launched at the end of February 2002 under the chairmanship of V. Giscard d'Estaing, with the intention of reporting by the summer of 2003. In essence, the final report was optimistically conceived as delivering a consensus view as on the relative rôles of the European Commission, the European Parliament, and the European Court of Justice, with an intent to convert the EU into a 'superpower' with a federal military force, police, and currency, in addition to the steady accretion of central powers. Throughout the period of preparing the report and subsequent governmental discussions, there was a fundamental divide between the eurosceptics who wished to sustain individualistic nation states, and the integrationists that favour uniformity.

Economic frailty prevailed in the euro-zone, despite the administratively successful introduction of a common currency, and the political desire to create a common European identity and transparent pricing throughout the euro-zone countries. Failure to rectify the economic structural deficiencies and differences within the zone, reduced earnings of US affiliate companies, and growing budget deficits in France, Germany, Italy, and Portugal did not fully compensate for the beneficial effects of favourable exchange rates on export earnings. In 2003, France followed Germany, Italy, and The Netherlands into recession. The Stability and Growth Pact limiting budget deficits to a maximum of 3% came under political re-interpretation from France and a recession-hit Germany. As a result of inflexible labour markets with high social taxes, unemployment rose to 8.3% in 2002, with unemployment of the under-25s at 16.4%. Employment continued to decline in agriculture and manufacturing industry but rose in the construction industries.

UK Economic growth in the UK exceeded that of its European G-7 partners, and was heading for a record thirteenth consecutive year of economic growth. Agricultural output was mixed as cheap imports competed with home-grown products on the supermarket shelves; a recovery in livestock was noted post the foot-and-mouth disease crisis. Consumer confidence was sustained despite the fall in equity valuations and reduced earnings. A combination of particularly low interest rates and extraordinary annual rises in house prices mainly in the south-east of England, Edinburgh, and Cardiff, led to unprecedented levels of household debt. By mid-2003, household debt in the UK reached £906 billion, secured lending £737 billion, credit-card debt totalled 7% of income, and unsecured debt grew at 15% *per annum*. At the same time, there were growing concerns about the viability of a large proportion of private-sector pension plans, low returns from savings, and the lack of confidence in financial institutions. About 2.5 million new cars were sold in 2002, raising the number of cars on UK roads to 25 million. Provisional data on unemployment pointed to a slight rise from 5.1% to 5.3% of the workforce, barely easing a tight labour market that in certain sectors attracted immigrant workers. Manufacturing industry suffered sharp declines and there were severe pressures on employment in financial services. The rapidly expanding public sector, especially in health, education, and transport, coupled to falling taxation revenues, led to a near doubling of the public-sector borrowing requirement to about $32 billion in 2002-2003. UK national accounts and its recent economic history were overhauled in September 2003 by steep revisions to the data issued by the Office for National Statistics (ONS). Continual substantial alteration to the data raised questions over validity of the direction of the decisions taken by the Bank of England's Monetary Policy Committee, as well as by investors and traders, based on the credibility of ONS assessments.

Countries in Transition Growth in the countries in transition ranged from 4.6% in the Commonwealth of Independent States (CIS) and Mongolia, 4.4% in Russia, to 2.7% in Central and Eastern Europe. Much-needed reforms to the economic structures of the CIS countries continued, and Russia began enforcing more robust financial discipline and better standards of corporate governance.

LDCs For the LDCs, there were mixed fortunes. Africa as a whole was of special concern: corruption, political and economic problems, long-standing civil unrest and armed conflicts, and various diseases impeded progress. The World Health Organisation (WHO) reported that in 2002, 29.4 million people in sub-Saharan Africa suffered from HIV/AIDS. South Africa continued with its high economic growth rate of 5.2%, and inflation eased somewhat. The Nigerian economy contracted by about 2%. In Asia, there was for the most part a rapid adaptation to the improving import-friendly US economy. The Chinese economy derived great benefit from a currency (renminbi) tied to the US $ as well as from FDI and technology inflows into its export industries, whilst its indigenous industry and agriculture remained inefficient. The poor monsoon in India did not detract from a 5% growth in GDP, and both China and India targeted high-value industries and activities. Healthy growth of 4.9% was recorded in the newly industrialised countries of Hong Kong (a part of China), Singapore, South Korea, and Taiwan. A 3.6% expansion was noted in the Association of Southeast Asian Nations' 'group of four' *viz.* Indonesia, Malaysia, the Philippines, and Thailand. Elsewhere, the Latin American economies contracted, exacerbated by a financial crisis in Argentina. Growth of 3.6% in the Middle East was forecast by the IMF, although Israeli output declined and the region was troubled by security problems, fluctuations in oil prices, and a decline in tourism.

International Trade International trade was forecast by the IMF to have risen in volume terms by 2.1% during 2002, recovering from the 20-year performance dip in 2001. Nevertheless, it was the second year in succession when the rate lagged behind the increase in global output. In 2003, the money borrowed by investors to trade in stocks and shares started to rise as a percentage of overall consumer debt, but did not approach the level of 20% recorded in 1999-2000. In terms of value, the rise in world trade was 3.1% to a projected $7.7 billion of which $6.2 billion was merchandise rather than services. The strongest growth markets for global exports came from the LDCs and countries in transition, with the volumes of their exports projected to have risen by 3.8% and 6.9%, respectively. These data contrast with 1.7% for the MDCs. Similarly, on the supply side, LDC exports rose by 3.2%, countries in transition by 5.3%, but MDCs only by 1.2%. The strongest recoveries occurred in the USA and the IT-producing and exporting countries in East Asia. Largely as a result of weaker currencies, EU and Japanese export growth was faster than that of imports. This was the reverse of the position in the USA where there was a surge in merchandise and services imports.

Exchange rates affect trade balances, capital flows, growth rates, profits, share prices, inflation rates, the costs of travel and holidays, the prices of oil and computer chips, and the relative sizes of economies. LDCs, in particular, have enormous difficulty in managing the risks of exchange-rate volatility. Momentum grew in 2003 for downward pressure on the exchange rate of the US dollar relative to the euro, pound sterling, and the Japanese yen. Foreigners started to switch from investing to become net sellers of US shares, leaving the USA exposed to purchases by other governments in US Treasury bonds, and net capital inflows to the USA started to decline.

A recovery on the world economy would be advantageous to Scotland as its economy is heavily dependent on exports. Even so, growth in the Scottish economy over the past two years was weaker than nearly all other regions of the UK, with low business investments, high business rates, low numbers of business start-ups, high water charges, poor revenue-generating patents and licences *per capita*, depopulation and an aging population, more than half the economy in the public sector, and profound public-sector mistrust of the private sector. (see also **Populations and Conflicts**)

OECD Scoreboard The biennial OECD science, technology, and industry Scoreboard revealed in 2003 the transformation of the Chinese economy. Using data in terms of purchasing power parity, total R&D spending in China in 2001 was estimated at $60 billion, behind that of Japan ($104 billion), and the USA ($282 billion). Around 60% of the R&D spend in China was from the private sector. Across the OECD membership, R&D spending as a percentage of total output in 2001 was 2.3%, a figure exceeded by Sweden (4.3%), and the USA (2.8%); in China it was 1.1%, but its annual rate of growth, adjusted for inflation, in recent years has been 10-15%. Eurostat, the statistical service of the European Commission add weight to OECD reports, noting that EU member states allocated 1.99% of their GDP to R&D in 2002, compared with 3.11% in Iceland, 2.98% in Japan, and 2.8% in the USA. Member states above the EU average were Belgium (2.17%), Denmark (2.4%), Finland (3.49%), France (2.2%), Germany (2.49%), and Sweden (4.27%). Member states at or below the average were Austria (1.94%), Greece (0.67%), the Republic of Ireland (1.17%), Italy (1.07%), Luxembourg (1.71%), The Netherlands (1.94%), Portugal (0.84%), Spain (0.96%), and the UK (1.84%). It was estimated that in 2002, €182 billion were spent on R&D in the EU.

Computing While the computer technology industry suffered from stock-market downgrades and large-scale redundancies, the technology itself experienced another dynamic year. Web sites, individuals, Internet service providers, and groups that operated high-speed networks exercised the music-recording industry that grew increasingly perplexed about unauthorised free music distributed over the Internet. Progress in the adoption of broadband Internet access was disappointing, with the majority of users dependent on the slower and lower capacity dial-up Internet access. Likewise, the adoption of computer applications available over the Internet was slower than projected.

Internet access varied across several countries, such that the UN expressed concern about the disadvantage conferred by not having on-line access – the so-called 'digital divide'. According to the UN International Telecommunications Union (ITU), more than 80 countries had fewer than 10 telephone lines for every 100 inhabitants, and in 60% of countries, fewer than 1% of citizens used the Internet. Furthermore, in its Digital Access Index 2002, the ITU noted that accessibility to information and communication technology in 178 countries was not dominated by the English-speaking countries. The top 12 in the ranking, where a score of 1 represents universal access and use, were Sweden (0.85); Denmark (0.83); Iceland and South Korea (0.82); Norway, the Netherlands, Hong Kong, Finland, and Taiwan (0.79); Canada and the USA (0.78); and the UK (0.77). In 2002, according to the OECD, websites *per* 1,000 people reached 84.7 for Germany, 71.7 for Denmark, and 66.4 for Norway. Both the UK and USA had more than 60 sites. The OECD average was 30, and the EU average 39.

University and college students throughout the world were major Internet users to the point that conventional libraries were becoming neglected. Plagiarism was facilitated by accessing the Internet, particularly sites that sold essays, theses, and reports, although the existence and deployment of web-plagiarism checkers or verifiers were thought to have restrained the level of examination cheating, as much as the variable quality of the material for sale. Other types of cheating, including unauthorised use of computers to access examination questions, faking credentials and certificates, and modifying marking records, merited a new type of vigilance by examination authorities and employers.

Dramatic increases were noted in the onslaught of infuriating unsolicited commercial e-mail - spam. As a highly cost-efficient method of distributing advertising, often anonymously, the spam perpetrators patently included hackers, distributors of worms and viruses, and pornographers. Internet marketing was also dogged by issues of privacy, notably those companies that without gaining customer authorisation placed 'cookie' files on consumers' computers to track Web surfing. Some areas of marketing did not grow as fast as anticipated *e.g.* on-line education, digital subscriptions to newspapers, magazines, and scientific journals.

Computer security exercised governments in 2002. The vulnerability of Internet servers, notably the 13 that handle the Domain Name System, was tested by terrorists, foreign governments, or hackers, but withstood the onslaught of bogus communications. Computer intrusions were detected in US government laboratories and military establishments. Development of methods of identification, *e.g.* electronic signatures; recognition of fingerprints, faces and eye patterns; voice scans; complex codes, and combinations of these were all under consideration.

The Semiconductor Industry Association estimated that global semiconductor sales rose by 1.8% in 2002 to $141 billion, with expectations of greater rises in 2003 and 2004. Asia was the largest market and continued to grow, in contrast to the US, European, and Japanese markets. Sales of dynamic random-access memory chips and digital signal processors rose sharply, whereas flash memory, analogue products, microprocessors, optoelectronics, metallic oxide semiconductor programmable logic devices, and microcontroller sales were depressed. Telecommunication companies worldwide experienced a particularly poor year in 2002, as major players suffered large losses, bankruptcies, redundancies, restructuring, and even criminal investigations. WorldCom Inc., Global Crossing, and Qwest Communications International were the subject of US criminal investigations, and state-owned or-controlled telecommunication companies in France and Germany were forced to appoint new heads.

Exploitation of the electromagnetic spectrum and the digitization of data have enabled the rapid development of wireless technology into mobile telephones, wireless-connected laptop and hand-held computers, personal digital assistants (PDAs), interactive televisions, global-positioning-system devices, and surveillance systems including the monitoring of the state of health of individuals, livestock, crops, and the environment. Two short-distance technologies began to revolutionise wireless access – Bluetooth and wireless fidelity (the latter also referred as wi-fi or 802.11). By April 2002, it was estimated that one billion personal computers (PCs) had been produced, with the most advanced PCs offering processor speeds approaching and sometimes exceeding 3GHz. Portable Tablet PCs with touch-sensitive screens to recognise and convert handwriting into conventional text, were introduced by several manufacturers, and large-capacity third-generation (3G) networks were planned. Mobile telephones using 3G will be able to send and receive 344Kbps compared with the usual 9.6Kbps. There is now pressure to launch 4G Internet technology to run at speeds ranging from 100 Mbps in cell-phone networks to 1Gbps in local wi-fi networks. Microsoft's Windows faced competition from free or low-cost versions of the Linux operating system which were becoming more popular in industry and scientific applications. Off-line computer and video games prospered such that game and hardware sales were estimated to be worth in excess of $10.5 billion in 2002.

Imports and Exports Analysis of the balance-of-trade data reveals the shift in the balance of trade towards the LDCs, with a rise of 3.2% in the value of exports over 2001. Nearly 50% of the $1.32 trillion value of exports arose from Asian LDCs, and together with trade in services and other transactions, LDCs overall returned a surplus on current account. The surplus was expressed most strongly in the Asian LDCs, but also occurred in the Middle East, including Turkey. A trade surplus in Latin America was more than eliminated by other current account transactions leading to a $32.6 billion deficit, and there was a $7.2 billion deficit in Africa.

Of the G-7 countries, only the USA and UK had current-account deficits, but the scale of the US deficit, at $480 billion dwarfed those of other countries. The UK deficit was $32 billion. Surpluses were recorded in Japan ($119 billion), most of the non-G-7 MDCs, the euro-zone generally, and the Asian NICs ($58bn).

Stock Markets It was testament to corporate scandals, profit downgrades, and global political instability that 2002 ended as the third successive year of a global bear market, the longest since 1945. According to the *Financial Times* and *The Wall Street Journal*, all of the major world stock market indices fell during 2002 between –4% (Mexico, 1PC) and –44% (Germany, Frankfurt Xetra DAX), with one exception (Thailand, Bangkok SET) which increased by 17%; none ended on a year-end low. Most analysts predicted that equity stock prices would rise in 2003.

Commodity markets performed well in 2002 and early 2003, as evidenced by the Economist Commodity Index (US dollars) for All Items as at the end of November 2002. Oil rose by 57.3%, food commodities by 17.1%, and gold by 16.4%. The threat of war with Iraq in 2002, realised in 2003, more cohesion in the organisation of Petroleum-Exporting Countries (OPEC), and a strike by oil workers in Venezuela, engineered higher oil prices. Gold benefited from its perception as a safe haven supplementing holdings in costly and dividend-generating defensive stocks, in uncertain times. The prices of silver and most base metals were constrained by high reserve stocks and reduced industrial activity. Agriculture looked forward to firmer prices.

At a time of a depressed investor climate and weakened corporate performance, interest rates in the MDCs remained subdued and stable throughout 2002. Central banks sustained low-interest-rate policies although at the end of 2002 and early 2003, the Australian Reserve Bank, the Bank of New Zealand, and others strengthened rates slightly in order to head off signs of inflation and economic overheating. The US dollar and pound sterling maintained their exchange rates for much of 2002 and early 2003, although early in 2002 there was appreciation against the Japanese yen and the euro.

Banking Globalisation as a phenomenon was demonstrated by developments in the international banking industry. In addition to addressing difficulties posed by the weak stock markets, several countries attempted to upgrade the regulatory and legislative arrangements governing their financial markets. New requirements were introduced to combat money laundering and the financing of terrorism, and adjusting to the extra-territorial implications of the US Sarbanes-Oxley Act. Particular emphasis was placed on conflicts of interest, corporate governance, auditor relationships, the nature and veracity of financial reporting, and disaster-recovery and business-continuity issues.

Competitiveness Assessment of growth and business competitiveness should be a prime activity of national governments. The World Economic Forum's *Global Competitiveness Report* for 2003 ranked countries for prospects for economic growth, and the efficiency of business as judged in surveys of international business executives (Table 2). Were it not for the deteriorating public finances of the USA, it would have topped both sets of rankings; significant also was the high ranking of the Nordic countries with their propensity to adopt new technologies and sustain robust public institutions. A perceived decline in the quality of its public institutions and facilities accounted for the relatively lowly position of the UK in 15th place. Although not an indication of corporate behaviour, the data indicate the climate for business.

In contrast to this analysis, however, the Entrepreneurial Framework Index 2002, derived from Apax Partners Ltd. and the *Economist* Intelligence Unit, measured countries on a scale of 0 to 10 that are low on bureaucracy ('red tape'), accommodating to private enterprise, have an equitable taxation regime, an open and well-developed financing system, flexible labour markets, and a modern, networked infrastructure. The rankings were both historical (covering

Global competitiveness index

Rankings	2003	2002
Finland	1	1
US	2	2
Sweden	3	3
Denmark	4	4
Taiwan	5	6
Singapore	6	7
Switzerland	7	5
Iceland	8	12
Norway	9	8
Australia	10	10
Japan	11	16
Netherlands	12	13
Germany	13	14
New Zealand	14	15
UK	15	11
Canada	16	9
Austria	17	18
South Korea	18	25
Malta	19	-
Israel	20	17

Business competitiveness index

Rankings	2003	2002
Finland	1	2
US	2	1
Sweden	3	6
Denmark	4	8
Germany	5	4
UK	6	3
Switzerland	7	5
Singapore	8	9
Netherlands	9	7
France	10	15
Australia	11	14
Canada	12	10
Japan	13	11
Iceland	14	17
Belgium	15	13
Taiwan	16	16
Austria	17	12
New Zealand	18	22
Hong Kong	19	19
Israel	20	18

Table 2. Global Competitive Rankings of 20 Countries

1997-2001), and forward-looking (covering expectations from 2002-2006), and led to seven of the top ten places filled by European countries: The Netherlands (8.44), UK (8.39), USA (8.34), Germany (7.92), France (7.87), Belgium (7.75), The Republic of Ireland (7.74), Hungary (6.4), the Czech Republic (6.33), and Poland (6.31). This analysis was supported strongly by the Economist Intelligence Unit's global business environment rankings in July 2003, an analysis which measured the quality or attractiveness of the business environment, considering 70 factors, across 10 categories, which affect the opportunities for, and hindrances to, the conduct of business. The model was used to generate scores and rankings for the next five years, and across the 60 largest countries there was a domination by European countries: The Netherlands (8.64), UK (8.54), USA (8.47), France (8.12), Germany (8.11), Austria (7.87), Italy (7.43), the Czech Republic (7.3), Hungary (7.12), and Poland (7.07). In a study released in June 2003 by the OECD of its 28 member countries, rankings were made of FDI restrictions during 1998-2000 in terms of (a) restrictions of foreign personnel and operations, (b) screening requirements, and (c) limits on foreign ownership. The results varied from the UK with the lowest barriers to foreign direct investment, through the Republic of Ireland, The Netherlands, Germany, Denmark, Belgium, Italy and France, all with slightly higher restrictions, to the USA and the Czech Republic with more restrictions, to the relatively highly restrictive environments in Japan, Australia, and Canada. Many countries and companies compare their business environments with the USA and are influenced by analyses such as the KPMG *Competitive Alternatives Report 2002*. Using a comparison based on the after-taxation cost of start-up and operation for 12 specific types of business over a 10-year period, and using the USA as the benchmark, the percentage cost advantage or disadvantage was estimated in a 10-month research programme covering over 1000 business scenarios in 85 cities in Austria, Canada, France, Germany, Italy, Japan, The Netherlands, UK and the USA. The rankings varied from the cost-advantaged countries of the UK (+13.1% cost advantage), Italy (11.4), The Netherlands (9.2), France (7.8), and Austria (6.3), through to Germany (-1.9% cost disadvantage). Another influential analysis is the annual *Tax Misery Index* published by Ernst and Young in *Forbes Global*, the latest in May 2003. In this, the sum of the national fiscal and social tax maximum rates (*i.e.* corporate income tax, personal income tax, wealth tax, employer social security payments, employee social security payments, and value-added tax) were converted into percentage points. The results (the Republic of Ireland 90.3, UK 111.3, Germany 116.6, USA 117.6, Denmark 123.0, Japan 124.9, The Netherlands 129.9, Spain 135.5, Finland 135.5, Italy 145.0, Sweden 149.8, Belgium 153.1, and France 179.4) showed great variation. From a salary equivalent to £100,000, the percentage of remaining salary after taxation deductions in 2003 were estimated to be 67% in the UK, 63% in the Republic of Ireland and Spain, 59% in France, 58% in Italy, 57% in The Netherlands, 53% in Sweden, 49% in Germany, 47% in Belgium, and just 46% in Denmark. B. Benoit in the *Financial Times* in 2003 made the point that most of the factors shaping investment decisions – the vitality of a company's market, its ability to cut staff in hard times, or the nature of its corporate governance – tend to be country-specific. This is clearly demonstrated within the EU.

Arab World In the *Arab Human Development Report 2003*, published by the UN Development Programme, the existence of a pronounced knowledge gap was highlighted between the Arab world, once a culturally advanced and socially influential society, and the rest of the world. Indicators such as GDP *per capita*, years of schooling, knowledge attainment by gender, Internet penetration, numbers of computers *per* 1,000 people, newspaper sales, *etc.* pointed to the need for improvement. Progress, however, has been impeded by worldwide anti-terrorism policies that have been largely military and security-oriented. As a consequence, restrictive procedures introduced by some MDCs and adopted by some LDCs (including some in the Arab region) have created a situation inimical to human development. The authors condemned the Israeli reoccupation of Palestinian territories but did not name those Arab countries that obstruct 'the march of freedom'.

UN One of the most profound effects of the aftermath of 9-11, and the ensuing US-led toppling of the regimes in Afghanistan and Iraq, was a growing realisation that the United Nations needed to refocus its overall mission on human security, thereby challenging the international legal principle of national sovereignty underpinning the UN and a raft of other international organisations. It was accepted that the very actions and oftentimes inactions of states themselves that were responsible for the most part for the major violations of basic human rights, the very tenets of the UN, preventing pre-emptive or retaliatory military and economic activities to terminate these violations. Obscenely, the perpetrators of some of the worst atrocities were able to participate freely and gain a platform in the UN. For the first time, the USA was not elected to membership of the UN Commission on Human Rights, whose meeting in early 2002 failed to condemn gross violations of human rights. The USA stated its intention to rejoin UN Educational, Scientific and Cultural Organisation (UNESCO).

In September, 2002, two countries were welcomed as new members: Switzerland, the European centre for many UN activities and other international bodies; and East Timor (Timor-Leste), the world's youngest state and the 191st member of the UN, and one of the poorest countries in Asia.

The UN and its constituent agencies and associated bodies continued to face budgetary constraints arising from non-payments and slow payments from about half the Member States. Some countries preferred to support short-term, high-profile disaster-related projects, high-profile research projects, or projects that related directly to the self-centred interests of the funding country.

Commonwealth The behaviour of the government of Zimbabwe dominated meetings of the Commonwealth of Nations, the only global political grouping of countries besides the UN, although 2002 was a time for celebration of the golden jubilee of Queen Elizabeth II, the symbolic head of the Commonwealth. There was ample reason to believe that Zimbabwe was in violation of the 1991 Declaration of Commonwealth Principles. Following the recommendations of a 'troika' of leaders (T. Mbeki of South Africa, O. Obasanjo of Nigeria, and J. Howard of Australia), and the views of Commonwealth election observers, Zimbabwe was suspended for a year from the Councils of the Commonwealth, rather than be expelled, as African members resisted tougher punitive measures. Zimbabwe's aggressive land-reform programme, draconian powers to suppress opposition, attacks on black opponents and white farmers, manipulation of the judiciary and ignoring the judicial rulings, widespread food shortages, manipulation of food aid to punish opponents, and virulent attacks of the west generally and the UK in particular, did not alienate President Mugabe from most African leaders. One feature of the Commonwealth shared with the UN and EU, was the growing influence of non-governmental organisations (NGOs) in meetings primarily aimed at addressing the much-needed reduction in global poverty. The first example for the Commonwealth of extending the power and influence of NGOs took place in the meeting with Commonwealth Finance Ministers in September 2002. Some questioned the legitimacy of non-democratic bodies, often driven by activists, of being afforded undue influence in democratic structures.

Dependent States. Government-level discussions on joint UK-Spanish sovereignty over Gibralter were undermined by a referendum of Gibraltarians that overwhelmingly rejected joint sovereignty. Greater autonomy for Greenland and the Faroe Islands from Denmark was predicted by the results of elections in those dependencies.

Concerns over international taxation avoidance and evasion, drug smuggling, the effects of crime on tourism, and low returns from agriculture were the main issues in the Caribbean and Bermuda. In the Pacific Ocean region, France faced demands for greater autonomy from French Polynesia and New Caledonia. OECD observations on money-laundering led to the Cook Islands remaining on its blacklist. American Samoa was officially removed from the list of colonial territories by the UN General Assembly, accepting there was no tangible desire for independence.

Tax Havens Harmonisation of taxation policies expressly to combat tax avoidance and tax evasion in a rapidly globalising business environment has been a long-standing ambition of governments in LDCs and MDCs, not least as the taxation burden on populations continued its seemingly unstoppable upwards progression and the spending ambitions of the public sector grew. Building on the initiative of the OECD to eliminate harmful taxation practices, the UN began in 2003 to provide an active forum for global dialogue on tax issues, proposing that its *ad hoc* 25-member group of experts on international taxation matters be upgraded to a formal intergovernmental body reporting to the UN's Economic and Social Council. In 2002, the OECD had blacklisted Andorra, Liberia, Leichtenstein, Monaco, the Marshall Islands, Naura, and Vanuatu, in addition to the Cook Islands, as tax havens. Despite its value in fighting crime and terrorism, it was expected that harmonisation would be resisted by countries wishing to sustain their sovereignty and competitive position. The tax-haven status and thus the economic standing of the Cayman Islands, a leading centre for hedge funds, was threatened by the EU savings directive. Smaller offshore financial centres complained that in 2003 Switzerland and Luxembourg, supported by Austria and Belgium, blocked agreement in the OECD on access to banking information for verification of tax liabilities from 2006. During 2002-2003, there were transfers of several banking operations from the EU to Singapore, a non-OECD member, which has resilient bank-secrecy laws and a well-regulated financial sector.

Populations and Conflicts

Global Populations In *The Sex and Age Distribution of the World Populations,* a UN report, the global population was estimated to be 6.158 billion in 2000, projected to reach 7.032 billion by 2010, 7.887 billion by 2020, and 9.833 billion by 2050. Between 2000 and 2050, substantial growth in population was projected to take place in Africa (0.832 billion to 2.141 billion), Asia (3.754 billion to 5.741 billion), Latin America (including Mexico and the remaining countries south of the USA) (0.524 billion to 0.839 billion), and Northern America (0.306 billion to 0.389 billion). Europe, on the other hand, is expected to decline from 0.730 billion to 0.678 billion. UN forecasts were revised down in 2003 on the basis of a projection of 278 million deaths from AIDS up to 2050, declining fertility rates in most parts of the world, the impacts of migrations, and expectations of high population growth in several LDCs. From population estimates for 2003, the world population is set to expand from 6.301 billion in 2003 to 8.919 billion in 2050. Growth is expected in Africa (0.851 billion to 1.803 billion), Asia (3.823 billion to 5.222 billion), Latin America (0.543 billion to 0.768 billion), and Northern America and the Caribbean (0.326 billion to 0.448 billion). A small increase is expected for Oceania (32 million to 46 million), but Europe is expected to shrink from 0.726 billion to 0.632 billion). That several countries have never held a proper census, and others have not held a census in recent years, means that the population data remain best estimates. What is clear, however, is that the global population is becoming more sophisticated and demanding in respect of diet, consumer goods, housing, communication, appearance, political expectations, and general lifestyle; market suppliers will need to accommodate these changes, many of which directly affect agriculture. The world is also becoming more urbanised. Over the last 100 years at a time when the population expanded from 1.6 billion to over 6 billion, there was only a slight increase in the land area farmed, although even now around one billion people use relatively primitive farming systems in the biodiversity-rich areas of the LDCs, particularly Southeast Asia, the Amazon area, and the Congo basin.

According to J. D. Wolfensohn, President of the World Bank Group, about 3 billion people live on under $2 a day, and over 1 billion try to subsist on under $1 a day. The 1 billion people in the MDCs have 80% of global income, and the remaining 5 billion in the LDCs have 20% of the income. In 1900, 14% of the global population lived in cities at a time when there were 233 cities of a million or more. In 2000, 2.9 billion people lived in cities, 47% of the global population. In 2020, 4 billion will live in cities, 60% or more of the global population, at a time when the average age of the population is expected to have increased. Urbanisation on this huge scale will require a change in culture and organisation, in the provision of services, and in the quality and scope of development frameworks. Poverty has to be dealt with in cities as well as the rural areas. Wolfensohn referred to 'glocalisation' as a means by which global issues are faced locally, with the sharing of knowledge and experience. Stable, adequate supplies of food and water are pivotal to addressing poverty alleviation.

Africa Africa continued to pose huge international problems for donor countries. In addition to massive population growth, diseases, and drought, the slow movement in democratisation held back human advancement. According to the UNDP, ranking of 173 countries in a Human Development Index for the year 2000 (based on achievements in Knowledge, standard of living, and a long, healthy life), placed only the Seychelles (at 47) in the high human development category; Libya (64), Mauritius (68), Tunisia (97), Cape Verde (100), Algeria (106), South Africa (107), Egypt (115), São Tomé and Principé (119), Namibia (122), Morocco(123), Swaziland (125), Botswana (126), Zimbabwe (128, undoubtedly sinking lower), Ghana (129), Lesotho (132), Kenya (134), Cameroon (135), Congo (136), and Comoros (137) in the medium human development category; and Togo (141), Madagascar (147) and the remaining Africa countries (148-173) in the low human development category. GDP *per capita* in 2000 in terms of $ purchasing power parity ranged from $10,017 in Mauritius, $9,401 in South Africa, and $7,570 in Libya, to just $668 in Ethiopia, $591 in Burundi, and an appalling $523 in Tanzania, a country rich in mineral resources. The UNDP provided a polity score for 2000, based on the presence of institutional factors necessary for democracy but not the extent of political participation. This score had a scale that ranged from 10 (democratic) to –10 (authoritarian). Democratic or emerging democratic countries in Africa were Mauritius (10), South Africa (9), Botswana (9), Senegal (8), Madagascar (7), Namibia (6), Benin (6), Mozambique (6), Mali (6), Côte d'Ivoire (4), Nigeria (4), Tanzania (2), Zambia (1), and Ethiopia (1). Authoritarian regimes were recorded for Libya (-7), Egypt (-6), Morocco (-6), Mauritania (-6), Eritrea (-6), Congo (-6), Zimbabwe (-5), Cameroon (-4), Tunisia (-3), Algeria (-3), Angola (-3), Burkina (-3), Togo (-2), Chad (-2), Guinea (-1), and Burundi (-1). A more recent analysis by the *Financial Times* in 2003 indicated that Cape Verde, Senegal, Mali, Benin, São Tomé and Principé, Botswana, and South Africa were fully fledged democracies, and nine others were emerging democracies, and the rest a mixture of aspiring democracies, pseudo-democracies, semi-authoritarian, authoritarian, and collapsed states.

UK Based on census reports of the Office of National Statistics, the estimated resident population of the UK in 2001 was 58,837,000 (28,611,000 male and 30,255,000 female); of which the population of Scotland was 5,064,000 (2,434,000 male and 2,630,000 female). In the *Annual Abstract of Statistics* (The Stationery Office), by 2011 the population of the UK and Scotland are projected to be 60,524,000 and 4,983,000 respectively. This differential is expected to increase by 2026, with a UK population aided by immigration of about 136,000 *per* year expanding to 63,156,000, of which the Scottish population will decline to 4,828,000, unless there is a sharp economic upturn. According to J. Randall, the Register-General for Scotland, the number of registered births for Scotland in 2002 fell to 51,270, the lowest figure since records began in 1855. More than half the population was over 39 years. There were more deaths than births, and the birth rate in 2002 was the lowest in the UK and one of the lowest in the EU. He was reported as stating that a declining population is a sign of weakening national identity and loss of international standing and economic confidence.

Agreements Following on from its stated intention in 2001 to withdraw from the 1971 Anti-Ballistic Missile Treaty with Russia, the USA formally announced in June 2002 its full withdrawal as it started the development of a ballistic missile defence system. Russia responded by withdrawing from the as-yet-to-be-implemented 1993 Strategic Arms Reduction Talks II with the USA. Nonetheless, in May, both parties had signed the Treaty of Moscow which obliged Russia and the USA to reduce their stockpiles of nuclear weapons by two-thirds over 10 years. Based on the 1987 Missile Technology Control Regime, the International Code of Conduct Against Ballistic Missile Proliferation was signed in November 2002 by more than 90 countries in an attempt to prevent the export of ballistic missiles and associated technologies to a group of countries of concern. In both 2002 and 2003, North Korea, a pathetic dictatorship of grave concern, admitted the possession and development of nuclear weapons, and refused to admit UN inspectors. It announced the end of the 1994 framework agreement to abandon its nuclear weapons programme in exchange for oil and nuclear energy plants. Both the UK and USA announced that they reserved the right to use nuclear weapons if they were attacked by biological or chemical weapons.

Most multinational and regional organisations were concerned with security threats, terrorism, and the prevailing economic situation during 2002-2003. The Association of Southeast Asian Nations (ASEAN) pledged to work with the USA in dealing effectively with terrorism, and a Regional counter-terrorism Centre was established in Kuala Lumpur. The Arab League approved a proposal to normalise relations between Israel and all Arab countries in exchange for Palestinian independence and borders based on 1967 boundaries. In June 2002, the African Union came into existence as the successor to the Organisation of African Unity and in October it established the African Economic Council and drafted the Nuclear Weapon-Free Zone Treaty to prohibit nuclear weapons throughout Africa. In the Americas, the Organisation of American States signed up to the Inter-American Convention Against Terrorism, and linked with the Caribbean Community to strengthen democracy in Haiti and Venezuela.

Conflicts Conflicts, many of which involved acts of terrorism, occurred in many regions of the globe. The Russian republic of Chechnya was ravaged by war, in an attempt by Russia forcibly to pacify rebels seeking independence for the republic. A tougher policy was adopted by Russia following the seizure by armed Chechens of around 800 hostages in a Moscow theatre in October 2002. During a storming of the building, 129 hostages died alongside 50 hostage-takers. Civil war in Colombia worsened as the authorities launched an offensive against the Revolutionary Armed Forces of Colombia (FARC), an organisation known to have links with international terrorist bodies. Two coup attempts were thwarted in Venezuela.

In the war-torn Middle East during 2002-2003, Israel carried out military offensives against Palestinians on the West Bank and Gaza, responding to suicide bombings. Suspected militants were imprisoned, some leading militants were assassinated, more tracts of land in the West Bank were forcibly annexed, and the movement of the Palestinians and their access to water impeded as their economy approached collapse. A Roadmap for peace in the region was produced by a group of nations.

Towards the end of the year, inspectors from the UN Monitoring, Verification and Inspection Commission (UNMOVIC) arrived in Iraq to assess the degree of Iraq's compliance with UN Security Council resolutions that demanded dismantling of its weapons of mass destruction. By that time, there had been a sharp increase in the number of incidents involving UK and USA aircraft patrolling the northern and southern 'no-fly' zones and Iraq's air-defence sites. On 20 March 2003, a brief war was launched by coalition forces against the regime of Saddam Hussein, leading to its downfall; on 1 May 2003 US President G. W. Bush declared that the war was over but that the war on terrorism would continue.

In South Asia, India and Pakistan alarmed the world with the possibility of nuclear confrontation following incidents in the disputed region of Kashmir and religion-based strife in both countries. After a period of posturing through the medium of testing new missile systems, the intensity of the conflict subsided. In Nepal, the vicious and poorly publicised war against Maoist rebels continued with little respite. Afghanistan remained unstable despite the presence of 4,500 troops from 19 nations belonging to the International Security Assistance Force, and 9,000 US troops. Factional fighting between ethnic groups and warlords, pockets of al-Quaeda and Taliban members, a disrupted transport system, leaky borders, and acute poverty faced the Interim Authority which was replaced by the Transitional Authority, both of which were headed by H. Karzai.

In East and Southeast Asia, government forces engaged in rebels and guerrilla movements in the Philippines and Indonesia. Likewise, in Africa, government forces fought rebel groups in Algeria, Angola, and Côte d'Ivoire, the latter conflict creating great difficulty for the headquarters of the West Africa Rice Development Association, chaired by N. L. Innes, the former Deputy Director of SCRI. A peace agreement was signed between the Democratic Republic of the Congo and Rwanda after the death over four years of about two million people. Angolan, Namibian, Zimbabwian, and most of the Ugandan foreign troops that had participated in the fighting were withdrawn. Uganda, with the approval of the Sudanese Government, despatched troops into southern Sudan to attempt to eliminate the rebel Lord's Resistance Army.

Religion Science on philosophical grounds often has a discomfiting relationship with the humanities and particularly with religion, but religious groups had violent relationships with each other during 2002-2003. Religious extremism and incompatibilities stoked up violence in many countries including Pakistan, India, Israel, the Palestinian lands, Tunisia, Russia, Ukraine, UK, Canada, France, Germany, Italy, and USA. Small-scale attempts were made to reconcile various faith groups, such as the initiative by the Anglican Archbishop of Canterbury to host an international conference between Christians and Muslims. Inflexible adherents to certain versions of their religious texts; scandals; resignations; differing attitudes to women, rituals, homosexuality, education, other religions, or atheism; and elements of ethnicity and nationality, constituted a challenge to international stability and understanding. For the scientist, I strongly recommend *The Hedgehog, the Fox, and the Magister's Pox: Mending and Minding the Misconceived Gap between Science and the Humanities* by the late S. J. Gould (Cape, ISBM 0 224 06309 X) and the brilliant review of the book by P. W. Anderson, the Nobel laureate, in *The Times Higher Education Supplement* p. 23, August 15 2003.

International Law Against the objections of the USA, the International Criminal Court (ICC) came into force in July 2002, following ratification by 81 member nations. The UN Security Council gave a one-year amnesty from prosecution to nationals from countries that had not ratified the ICC treaty (*e.g.* China, Russia, USA) and who were serving in UN peacekeeping duties. The exemption would be reviewed annually. The USA sought to reach bilateral ('Article 98') agreements with countries to provide immunity to US citizens to eliminate politically motivated anti-Americanism. International law was reinforced by rulings from the International Court of Justice, deciding a territorial dispute on the Bakassi peninsula between Cameroon and Nigeria, and agreeing with the Democratic Republic of the Congo (formerly Zaire) that Belgium failed to respect customary international law on the immunity of incumbent heads of state and their representatives. Two international criminal tribunals met during 2002 and 2003 – the International Criminal Tribunal for the Former Yugoslavia, and the International Criminal Tribunal for Rwanda; both had a backlog of cases, ensuring that with their slow rate of progressing cases, the tribunals would sit for the foreseeable future.

Terrorist Events According to the US Department of State, during 2001 and despite the September 11 attacks, the number of terrorist attacks fell to 346 compared with 421 in 2000, but 3,547 persons were killed, the highest number ever recorded. Concerted efforts to expose terrorists were directed towards the Al-Qaeda network, which demonstrated its effectiveness in causing two bomb explosions at Kuta Beach on the island of Bali, Indonesia, killing 180 and injuring more than 300 mainly young foreign tourists.

Drugs The production and trafficking of plant-derived drugs were influenced by three developments: (a) organised criminal groups were beginning to exploit the Internet sufficient for the International Narcotics Control Board to urge the creation of a UN Convention on Cybercrime; (b) large-scale poppy growing recommenced in Afghanistan boosting the opium (from which heroin, morphine, codeine, and papaverine are derived) trade; and (c) many governments switched their enforcement resources from the prevention of drug smuggling to combat terrorism.

Death Penalty Human-rights activists in 2002 sought to abolish the death penalty. More than 90% of the executions in 2001 were carried out in China (2,468), Iran (139), Saudi Arabia (79), and the USA (66). According to Amnesty International, 84 nations retained the option of using the death penalty whereas the penalty had effectively been abolished in 111 countries. Recent terrorist atrocities and popular sentiment would appear to overrule instances of flawed convictions and international pleas for clemency in those countries retaining the death penalty.

Bioterrorism Although a frequent topic of discussion over many years amongst biologists and security analysts, bioterrorism became a priority issue for most governments in the aftermath of the September 11 attacks and growing awareness of the activities of terrorist groups and governments bitterly hostile to western democracies. Most efforts on combating terrorism were focused on medicines to prevent and/or treat a range of highly infectious diseases. In April 2002, the Pharmaceutical Research and Manufacturers of America reported that 256 bioterrorism-related medicines such as vaccines, antiviral agents, and antibiotics, were under development. Existing antibiotics capable of countering a range of bacterial agents (*e.g.* anthrax, plague, tularemia) were being refined. Various governments made plans for the mass vaccination of their populations, with most emphasis on smallpox. An intriguing aspect of bioterrorism was the announcement in July 2002 that a poliovirus had been created over a period of two years by J. Cello, A. Paul, and E. Wimmer from its public-domain genome sequence using easily available scientific mail-order supplies. Oligonucleotides equivalent to parts of the 7741-base RNA genome of the virus were linked together and the DNA used as a template for RNA synthesis. The RNA was translated to form complete virus protein particles including fully infectious RNA-containing forms. Sequences of a diverse range of organisms are already in the public domain, as are the methods to construct a few simple viruses. Irrespective of fears about malevolent actions, there is the distinct possibility of creating artificial organisms to deal with intractable environmental problems, to synthesis pharmaceuticals, and to produce valuable polymers. Discussions on the potential for agriculturally related bioterrorism concentrated on the spread of livestock diseases, such as foot-and-mouth disease, and zoonoses, with relatively little attention paid to crop and forestry pathogens. Nonetheless, vigilance in the monitoring of meat, livestock, and plant imports, and monitoring of vectoring organisms are commonplace in the MDCs and are efficient mechanisms for counteracting both deliberate and inadvertent spread of pests and diseases. For scientists, there is likely to be a choice of self-regulation or governmental controls over areas of R&D that could be misapplied by terrorists. The US National Research Council identified seven R&D areas of concern: rendering a vaccine ineffective; conferring resistance to therapeutically useful antibiotics or antiviral agents; enhancing the virulence of pathogens; making a pathogen more contagious; enabling a pathogen to evade detection, such as removing markers; and making a biological agent or toxin useable as a weapon.

Refugees and International Migration The most authoritative source of information on the state of refugees and international migration is the UN High Commissioner for Refugees (UNHCR) who estimated that, in 2002, the number of people of concern to the organisation was 19.8 million, compared with about 21.8 million in 2001. The figure comprised 12 million refugees, as well as other categories of displaced or needy persons, especially asylum seekers (940,000), refugees who had returned home (returnees) but still needed help in rebuilding their livelihoods (460,000); local communities that were disrupted by the refugee movements; and finally the group termed internally displaced persons (IDPs; 5.3 million) that are not protected by international law and sadly are ineligible for most types of aid. In fact, as a result of internal conflicts, the UN estimated that there were in reality between 20 million and 25 million IDPs worldwide, with the major concentrations in Afghanistan, Angola, Bosnia and Herzegovina, Colombia, Democratic Republic of the Congo, Sri Lanka, and several countries of the former Soviet Union.

Not included in the mandate of the UNHCR were 3.9 million Palestinians who were the responsibility of the UN Relief and Works Agency for Palestine Refugees in the Near East (UNRWA). Another 350,000 Palestinians outside the UNRWA sphere of operations (*e.g.* in Egypt, Iraq, Libya *etc.*) were nonetheless considered to be of concern to it.

In a search for durable solutions to the sad plight of peoples of concern, the UNHCR continued to press for an integrated approach in partnership with Governments and other international agencies, involving the four 'Rs' - repatriation, reintegration, rehabilitation, and reconstruction. Voluntary repatriation is clearly the most sustainable solution for displaced persons, but where refugees are likely to face persecution or other pressures, UNHCR tries to arrange permanent resettlement, either in the country where they are given asylum, or in another willing recipient country. Only 20 countries, however, participated in official resettlement programmes and accepted very modest annual quotas of refugees in 2002, despite concerted efforts by UNHCR to diversify the resettlement base. MDCs that spurn refugees should be ashamed.

During the year, there was a dramatic increase in the numbers of returnees: over 1.5 million Afghans from Iran, Pakistan, and Tajikistan; 20,000 East Timorese from Indonesia; 17,000 Croatians from Yugoslavia; 15,000 Burundians from Tanzania; 11,000 Somalians from Ethiopia; and 10,000 Angolans from Zambia. By the end of 2002, official refugee status was removed from East Timorese and Eritreans commensurate with the reestablishment of more stable political conditions in their home countries. More peaceful conditions in Sri Lanka allowed by August the return of 1,000 refugees from India as well as the return of more than 183,000 IDPs, leaving a further 64,000 refugees in India and 620,000 IDPs to be cared for. Returnees, though, required and deserved assistance, beyond the current capacity of the cash-limited UNHCR.

New refugees and IDPs were created by conflicts in Africa and South America. Thus, in the eight months up to September 2002 more than 81,000 Liberians had fled the country, adding to the drain on the economies of neighbouring countries. Around 11,000 refugees from the Democratic Republic of the Congo entered Tanzania; 4,300 Sudanese went into Kenya, the same number into Uganda, and 2,000 into Ethopia. Some 5,300 Somali refugees sought refuge in Yemen, and 3,200 in Kenya. Around 4,000 Angolan refugees fled to Zambia. Official estimates of more than one million registered IDPs in Colombia were generally accepted to be only about one half of the actual number in that long-troubled country.

UNHCR reported that during the first six months of 2002, 9,300 refugees of 43 countries were resettled, with just 10 countries accounting for 94% of the total resettled; namely Afghanistan 2,400; Iran 1,170; Iraq 940, the Sudan 920, Bosnia and Herzegovina 700, Somalia 660, Vietnam 570, Croatia 420, Ethiopia 380, and Myanmar (Burma) 170.

Pending asylum applications at the beginning of 2002 were estimated to be 940,000, and should be seen in the context of (a) the events following the 9-11 events, and the declared war on terrorism; (b) a global economic downturn; (c) the rapidity of social change brought about migration; (d) the growth of human smuggling and trafficking (estimated by the US Administration to be a $10 billion a year 'business'; and (e) sensitivity towards economic migration. There was a global tendency to restrict immigration and access to asylum seekers. In October 2002, the UN Population Division published that the number of migrants worldwide had doubled since 1975, with most living in Europe (56 million), Asia (50 million), and the USA and Canada (41 million).

According to *World Migration 2003: Managing Migration – Challenges and Responses for People on the Move* (Geneva, International Organisation for Migration, 2003), the largest source of emigrants was Mexico, with a net outflow of 6 million people between 1970-1995, followed by Bangladesh (4.1 million) and Afghanistan (4.1 million), and then the

Philippines (2.9 million). The largest recipient of immigrants was the USA with a net inflow of 16.7 million between 1970-1995, followed by Russia (4.1 million), Saudi Arabia (3.4 million), India (3.3 million), Canada (3.3 million), Germany (2.7 million), and France (1.4 million). In absolute terms, of course, the greatest movements of populations occur within countries, mainly from the countryside to the towns and cities, reckoned to be 150 million in China alone. Pressures arising from these movements (social protection costs; environmental degradation; changes to ethnic, cultural, and religious mix of a recipient countries; modification of economic and political profiles *etc.*) can create barriers to the flows of people across national boundaries. M. Wolf of the *Financial Times* considered that the economic impact of immigration on the MDCs can be assessed in four ways. Firstly, there is little theoretical or empirical reason to believe that the narrowly economic benefits of immigration will be large for the rest of society, unless the immigrants are skilled or entrepreneurial. Secondly, immigrants into high-income countries tend to include large proportions of both highly skilled and unskilled people, but relatively few semi-skilled. Thirdly, economic benefits will fail to be realised if the immigrants fail to work – the unemployment rate of foreigners in 2000-2001 was about twice that of the labour force in Belgium, Denmark, Finland, France, The Netherlands, Portugal, and Sweden. Lastly, the effectiveness of immigration in stabilising the old-age dependency ratio (the proportion of pensioners to the working population) is limited because immigrants age, too. Immigration required by the EU to stabilise its old-age dependency ratio would increase its population to more than 1 billion by 2050, according to a report in 2000 by the UN. For LDCs, emigration represents a direct loss of human capital but can represent a source of remittances. Official remittances, deemed to be around half of total remittances, can be ranked by the ratio of a country's receipts to GDP. Thus, Jordan with 21.8% of GDP, followed by Yemen (13.6%), El Salvador (13.3%), and Jamaica (10./7%), top the recipients listings, but in absolute amounts, the remittances in 2000 of India ($11.6 billion, 2.5% of GDP), Mexico ($6.6 billion, 1.1% of GDP), Turkey ($4.6 billion, 2.3% of GDP), and Egypt ($3.7 billion, 3.8% of GDP) were the most significant.

Agriculture and Food

Global Production Global food supplies were adversely affected by drought in Africa, Australia, and North and South America. Crop and livestock production in Africa were also afflicted by widespread political instability and corruption. The global decline in grain output, by some 78 million metric tonnes (mmt), led to low ending stocks. In contrast, oilseed production only fell by less than 1% and meat output increased by 2.9%. Price increases were noted during the year in several of the major agricultural commodities. Global wheat production declined to 569 mmt in 2002, compared with 579 mmt in 2001, reflecting marked reductions in output from Australia, Argentina, Canada, and the USA, only partly compensated for by a sharp increase of 12 mmt to 104 mmt in the European Union (EU). Coarse grain production also fell from 887.5 mmt to 861 mmt reflecting droughted conditions in the main producing countries, counterbalanced by increased production in China and several of the countries of the former Soviet Union. Estimates of global cereal stocks for 2003-2004 by the European Commission's Directorate General for Agriculture support the view that only 130 mmt of wheat and a similar level of coarse grains will be available. Ending stocks of rice fell to 105 mmt in 2002 compared with 132 mmt in 2001. Largely as a result of a 7% reduction in the US soybean production, contrasting with enhanced production elsewhere, especially in South America, world oilseed production declined slightly in 2002 from the previous year.

Global sugar production increased from 134 mmt in 2001 to 139 mmt in 2002. Production increases were recorded in Brazil, China, the EU, and Russia. Consumption, to the concern of nutritionists, dentists and those opposed to the confectionary and much of the food-processing industries, continued to increase, aided by weakening prices.

Coffee also experienced low prices as global production increased to 125 million bags, principally as a result of enhanced production in Brazil. Cocoa prices, however, rose to 1986 prices as the civil war in Côte d'Ivoire, the world's largest cocoa producer, unsettled the markets. Non-governmental organisations (NGOs) such as Oxfam have pointed out the huge gulf separating the prices paid to growers and the retail cost of the processed cocoa and coffee products, highlighting the life-threatening vulnerability of small-scale growers. It is a fact that virtually all producers of agricultural commodities worldwide rarely benefit from value-added processes in the supply chain.

EU Agriculture Agriculture in the EU should be seen in the context of its interface with the rest of the world, and its relevance to the economic and social development of the Union. The EU remains the foremost importer of agricultural products in the world, and the second largest exporter after the USA; in 2000, the trade flows in agricultural products in the EU were around €58 billion for imports, and a similar figure for exports. In addition to its involvement in the WTO and OECD, the latter having its important Committee for Agriculture, the EU operates the Generalised System of Preferences in order to promote the integration of the LDCs into the world economy and the multilateral trading system, the UN's Food and Agriculture Organisation (FAO), as well as a series of bilateral and regional trade negotiations with the USA, Canada, Mercosur, Chile, South Africa, South Korea, Japan, the non-EU Mediterranean states, and the Balkan States. Within the EU, the pattern of spending on agriculture is split between market-related measures (Pillar 1), and rural development (Pillar 2). There is also spending under the Guidance Section of the EAGGF. Pillar 1 expenditure covers spending on market-related measures (*e.g.* direct aid to farmers, public intervention, export refunds), and measures to promote product quality. All Pillar 1 measures are funded in their entirety from the EU budget. Pillar 2 is designed to finance rural development measures such as agri-environment and early retirement schemes, training programmes, afforestation of agricultural land, and compensatory allowances in the less-favoured areas of the EU. Pillar 2 spend has a component of co-financing by Member States. According to Eurostat, in 2000, the shares of individual products in final agriculture production in the EU were (a) fresh vegetables including potatoes and fresh fruits 17.8%, milk 13.8%, beef and veal 10%, pigmeat 8.7%, cereals excluding rice 12.6%, wine and grape must 5.5%, poultry 4.1%, sugarbeet 1.7%, eggs 1.8%, sheepmeat and goatmeat 2.2%, oilseeds 1.9%, olive oil 1.8%, and the rest 17.8%. As a share in final agricultural production in the EU in 2000, there was great variation: France 22.7%, Germany 15.9%, Italy 14.9%, Spain 12.1%, UK 8.7%, The Netherlands 7.0%, Greece 3.9%, Denmark 3%, Belgium 2.5%, the Republic of Ireland 2.1%, Portugal 2.0%, Austria 1.8%, Sweden 1.8%, Finland 1.3%, and Luxembourg 0.1%.

Around 18% of the value of agricultural production in the EU is derived from the fruit and vegetable sector, and exhibits remarkable variety. Total vegetable production in 2001-2002 was around 55 million metric tonnes (Italy 15 mmt, Spain 12 mmt, and France 8 mmt); fresh-fruit production was around 57 mmt (Italy 18 mmt, Spain 15 mmt, and France 11 mmt). Interestingly, the 10 accession states produce around 9 mmt of vegetables and 6 mmt of fruit, dominated by Poland (5 mmt vegetables, 3 mmt fruit). Tomato production (15 mmt), citrus (10 mmt), apples (9 mmt), peaches and nectarines (4.2 mmt), dry onions (3.9 mmt), carrots (3.7 mmt), lettuce (3.2 mmt), cabbages (3 mmt), and pears (2.9 mmt) are the major horticultural crops, mainly addressing EU consumption of 43 mmt fresh fruit and 46 mmt of vegetables. Global production of fresh fruit and vegetables in 2001-2002, according to FAO, was around 1.230 billion tonnes, with fruit production around 470 mmt and vegetables around 760 mmt. The regional share of production was Asia 61%, EU 9%, North and Central America 9%, Africa 8%, and South America 7%. Preliminary data indicate a strong trend of increasing production. Although the EU has a fruit and vegetables policy (operating as a 'regime' for fresh fruit and vegetables, both covering a wide range of produce and products) the aim of the regimes is to encourage horizontal integration of producers and strengthen their market influence. Funds are made available for producer organisations, and for operational programmes such as product improvement and promotion. Assistance is also given under certain conditions to organisations involved in the processing of citrus fruits, peaches, pears, and tomatoes, as well as for the production of grapes for drying, dried figs and dried prunes, and for the storage of currants, dried figs, and sultanas. Likewise, production aid is given for almonds, hazelnuts, locust beans, pistachios, and walnuts.

The ornamentals sector accounts for 6.6% of agricultural production on the EU, covering cut flowers, potted plants, bulbs, shrubs, amenity trees *etc*. It is a sector that receives no EU financial assistance to producers, and no financial support through intervention purchases or export subsidies. Production is worth around €16 billion, with the main producers in value terms being the Netherlands (30%), Germany (16%), Italy (15%), France (14%), and the UK (7%). Danish and German consumers buy the most ornamentals in the EU (an average of €80 *per* inhabitant *per* year). EU exports were worth about €1.493 billion in 2001; imports in 2001 were about 8% of the value of EU production and are governed by WTO rules permitting application of tariffs and other measures to protect the EU industry.

Food Aid Famine was forecast by the World Food Programme and FAO in mid-2002 to threaten over 14 million people in Lesotho, Malawi, Mozambique, Swaziland, Zambia, and Zimbabwe. Shortly thereafter, 9 million more were considered to be at risk in Ethiopia and Eritrea. Several reasons for the need for food aid were given: drought; soil degradation; inadequate storage, transport, and marketing systems for seed, pesticides, fertilisers, and food and agricultural aid; poor agronomic practices; profound corruption, and crucially, political influences. Food aid was required by Afghanistan as its agriculture was disrupted by sporadic acts of terrorism and a diversion to lucrative poppy and heroin production. North Korea required food aid *via* the World Food Programme but its avowed intent to develop nuclear weapons and suspected support of rogue regimes alienated potential donor countries to this nation of paranoid nationalism.

CGIAR Agricultural R&D is conducted in most MDCs and LDCs, involving both the public and private sectors. The ability of agriculture to address poverty and hunger has a special resonance in an increasingly urbanised world and as populations in several LDCs continue to expand beyond the current productive capacity of their land. International trade and food aid alone are not able to address global needs at this juncture. It was, therefore, timely that the Consultative Group on International Agricultural Research (CGIAR) was established in 1971 to offer a strategic, science-based focus on developing technologies to benefit food-deficit countries and populations. The CGIAR is the oldest and largest of the global programmes supported by the World Bank, and consists of 16 autonomous research Centers employing 8,500 scientists and staff in more than 100 countries. It has 62 supporting members, comprising 22 MDCs, 24 LDCs, 12 international and regional organisations, and four foundations. It is co-sponsored by the World Bank, the Food & Agricultural Organisation (FAO) of the UN, the UN Development Programme, and the International Fund for Agricultural Development. The CGIAR's secretariat is housed in the World Bank, and its interim Science Council (formerly the Technical Advisory Committee) based in FAO. Since its inception in 1971, the CGIAR has received $930 million from the World Bank, and $4.67 billion from other donors. In 2003, the Operations Evaluation Department of the World Bank completed a review of the CGIAR – *The CGIAR at 31. An Independent Meta-Evaluation of the Consultative Group on International Agricultural Research.* This noted the outstanding achievements of the CGIAR and its crucial role in meeting the aim of the international community to halve global poverty by 2015. Notable though was the decline in expenditure during 1992-2001 on productivity-enhancing agricultural research and an increase in expenditure on improving policies and on protecting the environment, during a period when CGIAR funding declined in real terms, and the level of restricted funding (confined by donors to specific projects) increased from 36% of total funding in 1992 to 57% in 2001. Such constraints severely affected core research programmes. Factors that influenced the shift in expenditure and focus were thought to be a negative perception of the Green Revolution leading to a degree of unpopularity of germplasm-enhancement activities, the need to address the demands on soils and water through modern agriculture, the rise of environmentalism and its associated advocacy in donor countries, failure to fund adequately the national agricultural research systems (NARs) in LDCs – bodies essential to translate the outputs of the CGIAR Centers, and modification of the funding processes to a matching-grant model combined with incentives to pursue non-core work.

The CGIAR's Third System Review in 1998 had pointed out the importance of genetic resource management, the biotechnology revolution, intellectual property rights, and the increasing advances coming through private-sector agricultural R&D, an analyis that mirrored the conclusions of several reviews at SCRI in the late 1980s and 1990s, at a time when the CGIAR system has no formal or legal *persona*, written charter, or even a memorandum of understanding. Axiomatically, governance issues, revised priorities, natural resource management, and basic plant breeding and germplasm enhancement deservedly were regarded as essential factors in reforming and updating the CGIAR system.

In *Benefit-Cost Meta-Analysis of Investment in the International Agricultural Research Centres of the CGIAR*, produced in 2003 by the CGIAR Science Council Secretariat and FAO, justification for the investment in the CGIAR was analysed *ex post*. Such analyses are essential for all research bodies, but are rarely conducted. A relevant valuable resource book is *Crop Variety Improvement and its Effect on Productivity: The Impact of International Agricultural Research*, edited by R. Evenson and D. Gollin, 2003, CABI. On the basis of five benefits scenarios founded in various criteria of transparency and demonstration of causality, investment in the CGIAR reaped enormous benefit in all five scenarios; three research areas were highlighted – cassava mealy bug biocontrol, breeding of spring bread wheat, and breeding of modern cultivars of rice. Recommendations on reshaping the CGIAR system in the Meta-Evaluation included (a) the World Bank addressing its corporate governance responsibilities in managing the CGIAR, and thus encouraging donors to improve the level of unrestricted funding and abandoning the matching-grant funding model; (b) more prominence should be given to basic plant breeding and germplasm enhancement and refocusing the current research on natural resource management towards productivity enhancement and the sustainable use of natural resources for the benefit of LDCs; (c) reconfiguring the governance of the CGIAR system in order to improve clarity over roles, responsibilities, accountability, transparency, and efficiency to generate global and regional public goods.

It was under the guidance of the UN in 2000 that the eight Millennium Development Goals were formulated to target the essential areas of international cooperation needed to tackle poverty reduction, food security, broad-based economic development, and environmental development. As was stated at the time, agriculture holds the key directly and indirectly to achieving the Goals of (a) eradicating extreme poverty and hunger; (b) achieving universal primary education; (c) promoting gender equality and empower women; (d) reducing child mortality; (e) improve maternal health; (f) combating HIV/AIDS, malaria, and other diseases; (g) ensuring environmental sustainability; and (h) developing global partnership for development. The eight Goals were given a total of 18 targets, most of which had time-frames ending in 2015, and 2020 in the case of achieving a significant improvement in the lives of at least 100 million slum dwellers.

On the basis of current policy and investment trends, J. von Braun and colleagues at the International Food Policy Research Institute (IFPRI) pointed out in 2003 that it will not be possible to meet the 1996 World Food Summit Goal, one restated at the 2002 Millenium Summit, and the 2002 World Food Summit in Johannesburg, of reducing the food-insecure population of the world by at least 50% no later than 2015. According to FAO in 2002, the number of food-insecure people in LDCs fell from 920 million in 1980 to 799 million in 1999, representing 28% and 17% respectively of the global population. Present-day levels of food production, let alone potential, are more than adequate to provide minimal food quantities for a healthy existence of all the global population. The leading question is how to achieve an improvement in the world food situation, one that is being answered mainly by the CGIAR group. If China is deleted from the statistics on the number of undernourished people in the world, rather than a decline in recent times, hunger increased in the LDCs by 50 million in the decade up to 2000, mainly in Sub-Saharan Africa. IFPRI pointed out that in addition to simple assessments of calorie intake, it is essential to take into account micronutrient intake (*e.g.* iodine, iron, vitamin A *etc.*). The globalisation of the food system that has led to integration and a considerable degree of coalescence and growth in the food production, processing, and retailing industries, with new supply-chain configurations, has largely by-passed the poor and malnourished. Moreover, the failure of the Cancún negotiations (see section on **WTO**), in large measure prompted by the continuance of the US $75 billion annually in agricultural subsidies in the OECD member countries, constrains agricultural development in the LDCs, unless parts of their agricultural activity can integrate with MDC supply chains. Increased and equitable market access for key primary commodities from LDCs is seen by most economic experts as a prerequisite for poverty alleviation and development. That the prices of virtually all primary commodities are on a declining trend, dependent as they are on market forces and improving agricultural efficiency, re-emphasises the need for LDCs to have policies in place to improve competitiveness, diversification, and attractiveness to inward investors. Such needs, though, are easily stated but difficult to implement in a state of poverty and food insecurity. Some MDCs are beginning to insist on environment and labour provisions in trading agreements, recommending dispute-settlement processes with the possibilities of penalties and trade sanctions. LDCs often regard such provisions as poorly disguised protectionism; small-scale farmers would not be able to compete using MDC-ordained employment, health and safety, and environmental quality standards.

IFPRI recognised three sets of risks in the future: (a) adverse resource management and technology interactions (*e.g.* rapid climate-change effects, appearance of new types of pest and disease, mismanagement of water resources); (b) health-related food crises (*e.g.* further spread of HIV/AIDS and other epidemics, adoption of unhealthy diets); and (c) governance and policy crises (*e.g.* civil unrest and wars, collapse of small farms, decline in the quality of governance related to food and agriculture). IFPRI also developed its International Model for Policy Analysis of Agricultural Commodities and Trade in order to project future global food scenarios. These new scenarios were (a) a progressive policy actions scenario having a renewed focus on agricultural growth and rural development; (b) a multidimensional policy-failure scenario of conflicts and increased agricultural and other trade protectionism; and (c) a technology and resource management failure scenario. The benefits of the progressive policy actions scenario were dramatic, and the other scenarios remarkably bleak. Even in the most favourable scenario, improved water management is central to improvement, and regardless of this, fish will be one of a few food items whose prices will inevitably increase. By 2020, LDCs are projected to account for over three quarters of global fish production and consumption on current diet trends and fish farming will continue to expand as wild fish stocks are exploited at best to maximum sustainable levels or most probably to well beyond their productive capacity. Realisation of the progressive policy actions scenario will mean that donor countries will have to translate their declared support of agriculture and agricultural science and technology into meaningful actions.

WTO Criticism of the agricultural policies of the more-developed countries (MDCs) by the less-developed countries (LDCs) was voiced in the World Trade Organisation (WTO) multilateral trade liberalisation negotiations, originally launched in Doha, Quatar, in November 2001. Throughout 2002, the initial negotiating positions of the main countries were made public, as a lead up to the world trade talks at Cancún, Mexico, in September 2003, talks that eventually failed. The main positions were generally (a) improved access to MDC markets by LDCs; (b) the 17-member coalition comprising the Cairns Group of agricultural-exporting countries sought better access to markets and elimination of trade distorting domestic subsidies; (c) the USA proposed a tripartite enlargement of international trade by reducing domestic farm subsidies to no more than 5% of the value of agricultural production, a reduction of 15% in tariffs on agricultural products, and a 20% increase in the commitments to expand market access; (d) the EU appeared to be constrained by internal negotiations to be held in June 2003 but was known to oppose vigorously the elimination of subsidies for both production and export; and (e) Japan was reluctant to deviate from the existing WTO trade rules.

Agriculture is a defining topic of international trade. The multilateral trading system, created through the establishment in 1947 of the General Agreement on Tariffs and Trade and continued through its successor body, the 148-member WTO, is universally acknowledged as the lynchpin of global prosperity. Following on from the collapsed talks in Seattle in 1999, the failure of the Cancún negotiations of the Doha round bodes ill, notably for the LDCs that are usually dependent socially and economically on their agricultural sectors. Multilateralism could give way to wholesale bilateral arrangements between nations or trading blocs, or regional agreements, in concert with reinforced or sustained trade barriers. Ironically, the Doha round was aimed specifically at aiding LDCs. The World Bank had estimated that a gain of over $300 billion a year would benefit LDCs by 2015 as a result of freer trade and reduction or elimination of MDC trade-distorting subsidies. Prospects for completing the round by the end of 2004 seem to be unrealistic.

Although the four so-called 'Singapore issues' of competition, investment, government procurement rules, and facilitating trade, came into the reckoning in Cancún, agricultural protectionism was the most intractable matter, and was not confined to the 'subsidy-junkies' of the OECD countries. Special access arrangements for certain former colonies, and high import tariffs to guard against free trade are common to many LDCs, large and small. Nevertheless, the newly created G-22 group of LDCs (Argentina, Bolivia, Brazil, Chile, China, Colombia, Costa Rica, Cuba, Ecuador, Egypt, Guatemala, India, Indonesia, Mexico, Nigeria, Pakistan, Paraguay, Peru, Philippines, South Africa, Thailand, and Venezuela) railed against the framework for freeing up farm trade proposed by the EU and the USA, a framework that did not include the elimination of export subsidies. Failure to agree on the farming issues led to a group of African nations refusing to consider the four Singapore issues, and the talks collapsed. A combination of inflexibility by some of the MDCs on farm subsidies, unrealistic expectations by some LDCs, and inflammatory and intolerant advice given to LDCs by a large number of NGOs at Cancún, meant that the WTO could not reach a consensus. As the WTO is the only international arena where all countries, LDC or MDC, have a veto, and thus where poor countries have influential positions, the Cancún fragmentation suited only those opposed to globalisation but severely weakened the economic position of the poorest countries.

Domestic political issues in 2004, coupled with a growing protectionist attitude in both the USA and EU could delay the restart of the Doha round after the failure of the Cancún talks, notwithstanding any pressures that may be brought about by the new coalition of developing countries. Greater priority started to be given to bilateral free-trade agreements. Within the EU, enlargement and emphasis on trade with non-EU Mediterranean countries gave the impression of introvert approaches to agricultural trade. Free-trade agreement with Asian countries could lead to a lowering of a multilateral thrust to international trade, too. Agriculture frequently lies at the heart of the difficulties exposed in WTO talks. Subsidies, tariffs, and quotas undoubtedly distort trade but do underpin land values, rural incomes, and a large tranche of public-sector employment in the MDCs, as well as generating international legal debate. Malcontentment expressed by LDCs and certain NGOs over the impacts of the Uruguay round and the establishment of the WTO in 1995 is largely unjustified. LDC exports in the period 1995-2001 grew twice as fast in value terms as total global exports; excluding China, LDC-exports grew 50% faster, and as the Multi-Fibre Arrangement is phased out at the end of 2004, growth will be further enhanced. Restarting the Doha round would appear to require the subsidy-dependent agricultural systems of certain MDCs to change tack, as well as reviewing the Derbez text on negotiating a wider Doha mandate, plus some form of transitional arrangements for LDCs to adapt to the rules of international trade.

Anti-globalisation has been manifest in the form of placid as well as violent demonstrations, activist-led events and campaigns as 'Buy Nothing Days', anti-brand movements, publications, conferences *etc*., and is founded on a variety of strands of thought, including: anti-capitalism and anti-profit; anti-consumerism; hostility to Americans and the USA; anti-MDCs; anti-multilateral organisations such as the EU and WTO that promote multilateral trade; anti-private sector; anti-science and technology; anti-modernity; anti-multinational corporations; anti-global inequality of wealth (sometimes with a measure of guilt by unemployed social-welfare-dependent protestors from MDCs); asset-stripping of LDCs by MDCs; resistance to the creeping uniformity of once-diverse societies and the loss of regional and ethnic identities; cultures and languages; resentment over the economic and social failures of Communist-controlled or inspired countries; and sometimes the wish to indulge in anarchy. Often, anti-globalisation has brought with it benign or uncritical acceptance or corrupt, extremist, or inefficient regimes in the LDCs; the grinding poverty of a subsistence-level existence; and an unwillingness to appreciate the roles and contributions of profits, specialisation, international trade and foreign direct investments, improved corporate governance and litigation, trends in the LDCs towards imitating the wealth-creation systems of the MDCs, scientific and technological advancements in food production and processing, and international communication systems that raise the expectations and desires of the poor. Utopian views of a democratically elected world parliament, unfettered transfers of wealth, societies and countries compelled to live in complete harmony, and compulsory public ownership of all assets have been stated frequently, but it has been argued that anti-globalisation takes form functionally in certain constraints and distortions in international trade through outright barriers, tariffs, and subsidies. Agriculture has been the high-profile focus for protectionism for centuries, but nowadays even certain aspects of the arts and creative industries have also received special protection in most MDCs, mainly through subsidies that hitherto rarely received the level of scrutiny accorded to agricultural support mechanisms. As J. Stiglitz, the Nobel Laureate, pointed out in *One economic model does not suit the whole world* (in *Guide to Global Corporate Social Responsibility*. International Chambers of Commerce UK, RSM International, Cyworks plc 2003) the problem is not with globalisation, but with how it has been managed. International economic institutions such as the International Monetary Fund (IMF), World Bank, and WTO have set rules that best suit the MDCs using one market model based on a set of doctrines, the Washington Consensus policies. Stiglitz suggests a number of reforms, including (a) due recognition of the dangers of capital market liberalisation and appreciation of the disruptive effects on LDCs of short-term capital flows, (b) bankruptcy reforms, especially recognising the special nature of bankruptcies that arise out of macro-economic disturbance, (c) adjusting the rôle of the IMF so that as a major creditor it does not sit in bankruptcy judgement, and (d) improved banking regulation to bring an end to bad lending practices. In the same volume, H. Köhler of the IMF in *Strengthening the framework for the global* *economy* proposed six guideposts to improve the globalisation process. (a) National policy agendas must recognise international interdependence. (b) National self-responsibility is an essential principle, as it is impossible to combat financial crises and poverty without better governance, a secure legal foundation, and less corruption. (c) Measurable and honest solidarity is required to combat world poverty, and the target set by the UN of 0.7% of GDP in development aid should be met. (d) National efforts and international cooperation need to be integrated to combat global ecological threats. (e) International standards and codes, promoting greater transparency, efficient financial market-supervision, and good corporate governance are needed for recognised 'rules of the game' to participate fairly in globalisation. (f) There should be respect for the diversity of experiences and cultures, and all countries should not be focused into a uniform economic model

Subsidies Subsidy arrangements in the USA and EU were elaborated during 2002-2003. In the USA, legislation enacting supplemental farm spending up to 2007, and multiyear legislation on countercycle farm support payments, represented substantial increases in subsidies. Further subsidy support would come from newly launched environmental protection programmes. In the EU, the mid-term review (MTR) of the Common Agricultural Policy (CAP) initially proposed cuts in subsidies and converting the remaining subsidies into production-neutral support linked to as-yet-undefined environmental objectives. This proposal was rejected in favour of the *status quo* for most EU countries, irrespective of strains that may arise with the accession of 10 states from Central Europe.

OECD The OECD came into force in 1960 with the aim of promoting (a) policies design to achieve sustainable economic growth, employment, and financial stability in member countries; (b) sound economic development in member countries as well as LDCs; and (c) expansion of world trade on a multinational basis. The original member countries are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, the Irish Republic, Italy, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, UK, and the USA. Thereafter, ten other countries joined the OECD *viz.* Japan (1964), Finland (1969), Australia (1971), New Zealand (1973), Mexico (1994), Czech Republic (1995), Hungary (1996), Poland (1996), Korea (1996), and the Slovak Republic (2000).

In the *OECD Agricultural Outlook, 2003-2008, Highlights, 2003*, prepared by the OECD Directorate for Food, Agriculture and Fisheries, a series of economic and policy assumptions, together with various commodity production projections were used to forecast how global and domestic forces shape agricultural markets over the short to medium term. As a result of population changes, global dietary changes, and economic growth changes, it was projected that the world production of agricultural products would continue to expand over the period to 2008, reflecting in large measure continued productivity increase, especially in non-OECD countries (the Non-Member Economies). There will be a shift in outputs from food grains such as wheat- and rice-based staple foods towards more processed foodstuffs and high-protein products, especially meats. OECD markets are thought to be capable only of relatively slow growth. In the short term, drought, low demand arising from the global economic weakness, and market distortion caused by governmental support policies (notably in the EU, Japan, and the USA) are leading to divergent price trends for higher crop prices and depressed livestock prices, but this trend will readjust as the global economy improves. Improvement in market conditions would occur if agreement could be reached in the WTO agricultural trade negotiations. For OECD countries, the highest growth in net trade will be for cereals, especially coarse grains, followed by dairy products, when compared with average volumes for 1997-2001. A slowdown in meat exports is expected as internal consumption increases and international competition takes effect. Low global sugar prices are expected over the medium term.

UPOV In 2003, Poland became the 24th member state to deposit its instrument of accession to the 1991 UPOV (International Convention for the Protection of new Varieties of Plants) agreement.

GM and Organic Crops As a result of health interests as well as food scares, livestock-related diseases, food poisoning, and the prospect of terrorist attacks, food quality, safety, and labelling were high-profile issues through 2002-2003. Genetically modified organisms (GMOs) and GM products were especially contentious, as the EU continued its opposition to the importation of GM foods until they were shown unequivocally to be safe for human health and the environment. It was stated that all GMOs in food must be listed by shippers, and that products containing more than 0.9% GM materials must be labelled as such. These obligations were linked to extensive traceability and monitoring rules. Much of the hostility to and rejection of GM crops and products came from the expanding 'organic' farming lobby, environmental pressure groups, retailers that had specialist 'organic' interests, food-processing companies threatened by environmental activists and certain catering and restaurant interests encompassing the committed and the opportunistic. Despite an emphasis on a crop-by-crop, gene-by-gene, place-by-place analysis, GM crop technology as a whole has been condemned in the EU, leading to widespread vandalism and international trade distortion. In the USA, national standards for organic foods were adopted in October 2002 by the US Department of Agriculture (USDA). 'Organic' was taken to mean that the product is free of artificial colours, flavours and preservatives, as well as free from synthetic pesticides, artificial fertilisers and sewage, and GM components. Moreover, it would not have been subject to ionising radiation. For those products designated '100% organic', every ingredient except water and salt must be organic. "Organic" labels on products mean that 95% of the ingredients are organic, and "made with organic ingredients" must have at least 70% organic components. A lack of international agreements over labelling, and the capacity for cheating because of the subjective nature of self-imposed often unverifiable regulations, endanger the long-term viability of a substantial 'organic' food sector.

Legal challenge to the *de facto* or unofficial moratorium since 1998 on the approvals of new GMOs in the EU was initiated in the WTO by the USA, Argentina, and Canada. Various WTO members with a substantial interest in the dispute are joining the dispute as third parties, with a right to be heard by the dispute panel.

Further delays in agreeing new EU rules for the purity of seeds, including thresholds for the presence of GMOs, meant that the adoption of the new rules will be delayed into 2004, to the dismay of the biotechnology industry in Europe. The debate over labelling thresholds was not fully resolved, but EU Regulation No. 1830/2003 on the traceability and labelling of GMOs does not apply to foods containing no more than 0.9% of GM ingredients. Novel foods containing or derived from GMOs require labels specifying compositional, nutritional value, and known health implications.

By 2002, the global area of GMO (transgenic) crops reached 58.7 million hectares, grown by 5.5-6.0 million farmers in 16 countries, according to C. James in *Global Status of Commercialized Transgenic Crops: 2002*, published by The International Service for the Acquisition of Agri-biotech Applications, the source of valuable, accurate, and frequently cited Briefs on agribiotechnology issues. The 2002 area figure represented an annual rate of growth exceeding 10% since the commercial GM crops were introduced in 1996. Despite the endeavours of anti-GM activists and adverse publicity, 27% of the transgenic cropping area in 2002 was in nine LDCs. Even so, four countries accounted for 99% of the cropping area: USA (66%), Argentina (23%), Canada (6%), and China (4%). Just four crops were grown on a substantial scale: GM soybean (62% of area), GM maize (21%), GM cotton (12%), and GM oilseed rape (canola; 5%). Three dominant traits were used in the six-year period 1996-2002: herbicide tolerance (75%), Bt insect resistance (17%), and stacked genes (8%). A measure of the success of GM crops demonstrated in the marketplace was the fact that 51% of the global area of soybeans was down to transgenic crops, 20% of the global cotton crop, 12% of the oilseed rape crop, and 9% of the maize crop. Another telling statistic is that over 50% of the world's population live in countries where GM crops are approved and grown. Preliminary estimates show that the area of transgenic crops increased again in 2003. In 2002, small areas of commercial transgenic crops amounting to around 1% of the global total were grown in 12 countries in descending order: South Africa, Australia, India, Romania, Spain, Uruguay, Mexico, Bulgaria, Indonesia, Colombia, Honduras, and Germany.

C. James described succinctly the future of GM crops in international agriculture, principally in respect of their capability to contribute to (a) increasing crop productivity thereby improving global food, feed, and fibre security; (b) conserving biodiversity through the use of GM crops as a land-saving technology; (c) more efficient use of external inputs and a more sustainable environment; (d) increasing the stability of crop production thereby lessening suffering during famines caused by abiotic and biotic stresses; and (e) economic and social benefits, and the alleviation of poverty. He estimated an annual $4.4 billion investment in R&D in crop biotechnology, $4.22 million of which originates in the MDCs. The estimated value of the global transgenic-seed market was $4.066 billion in 2002, a 10.8% increase in value over 2001, according to Cropnosis Agrochemical Service, 2003, which also estimated the global crop-protection market in 2002 (herbicides, insecticides, fungicides, plant-growth regulators, and others, plus the transgenic seed market, to be £30.627 billion. The global commercial seed market was estimated to be £30 billion in 2000. Interestingly, market contractions were recorded in the herbicide (-6.8%), insecticide (-5.6%), fungicide (-0.3%), and growth regulator and others (-1.9%) sectors. These latter sectors amounted to $26.561 billion, $17.393 billion of which were in the MDCs. Of the total global crop-protection market, including transgenics, the USA accounted for 32% of the total, Japan 9%, Brazil 7%, China 6%, France 6%, Argentina 4%, Canada 3%, Germany 3%, South Korea 3%, Australia 2%, India 2%, Italy 2%, Spain 2%, and the UK 2%. On a crop basis, the crop protection market in 2002 was dominated by the fruit and vegetable sector (25%), followed by soybeans (15%), cereals (13%), maize (11%), cotton (10%), rice (9%), oilseed rape (canola) 2%, sugar beet 2%, and the remaining crops (13%). Monsanto's trading figures showed for the first time that the value of traits and seeds exceeded that of agrochemicals.

Elsewhere in this *Annual Report*, various aspects of GM crops are described, including the recent Farm-Scale Evaluation Trials, building on the series of articles in the *Annual Report* Series on this heavily debated, highly repetitive topic, one that I have been actively engaged in for the past two decades. Agriculture now is beginning to acquire the tools to integrate into a series of other industries and activities, holding the key to sustainable industrial production. It deserves fresh political and commercial eyes to convert this new vision into reality.

International Horticulture Recreational and amenity gardening and unprotected horticulture, in large parts of Europe and the USA were affected by long periods of drought in both 2002 and 2003, as well as by imported pests and diseases. Environmental impacts of high-intensity horticulture began to excite some scientists and pressure groups. Industry reports pointed to improving sales of bedding plants, whereas sales of trees and larger shrubs were relatively static or in certain instances, declining. Gardening programmes on television, such as *The Victory Garden* in the USA, and radio, such as *Gardener's Question Time* on Radio 4 of the British Broadcasting Corporation, remained popular. Throughout Europe and the USA, plans were announced to plant more trees, restore public gardens and parks, and create new public and private gardens. The profile of the major botanic gardens was enhanced by widening interest in conservation. Most prominent of the horticultural events during 2002 was the fifth Floriade, the World's Fair of horticulture, held between April to October in Haarlemmermeer, The Netherlands; it was attended by over two million people.

The Environment

See also sections on **UK Environment** and **UK Agriculture**.

Johannesburg A plan of action arose out of the World Summit on Sustainable Development ('Rio+10') that opened on August 26, 2002, in Johannesburg, South Africa. Attended by delegates from 192 countries, the EU, a variety of intergovernmental institutions, and environmental groups, the Summit was designed to review the implementation of the Agenda 21 plan formulated at the 1992 Rio Summit, but with special emphasis on social and economic issues. The plan of action set out laudable objectives such as halving by 2015 the proportion of the world's population living on less than $1 a day, suffering from hunger, and not having proper access to safe drinking water or improved sanitation. Within the same time-frame, child-mortality rates would be reduced by two-thirds, and maternal-mortality rates by three-quarters, compared with the base line of 2000. Other objectives included greater investment in cleaner and more efficient technologies, commitment to the Kyoto Protocol, reduction in the use of environmentally and health-damaging chemicals, maintenance of sustainable fish stocks, reduction of elimination on non-agricultural tariffs, the favouring of debt relief, and the attaining by MDCs of development aid to LDCs equivalent to 0.7% of their GDPs. The UN was seen to have a prime rôle in promoting sustainable development, and participating governments were committed to monitoring of progress to achieving the objectives. Agriculture had central role in the Summit, but received relatively little publicity. Outbursts by protesters and some governmental delegates soured the Summit, and lowered the attractiveness and value to donor countries of huge open conferences.

Environmental Deterioration The multi-authored report *Global Environment Outlook-3*, published in May 2003 by the UN Environment Programme (UNEP), considered that there has been steady global environmental deterioration, most notably in the LDCs. Four possible environmental scenarios over the next 30 years were reviewed: (a) markets-first, the current situation; (b) policy-first, led by stronger environmental legislation; (c) security-first, in which an unstable world of conflict leads to the wealthy MDCs establishing isolationist enclaves; and (d) sustainability-first, in which an effective global consensus is created dealing with environmental issues. It was thought that under the most optimistic scenario, (sustainability-first), environmental improvements would not be manifest for decades. This somewhat dismal projection was contested by many, not least B. Lomberg, author of the controversial book, *The Skeptical Environmentalist*. He and others maintained that environmental improvements are ignored and problems are exaggerated by pressure groups and vested interests; the problems will not be solved until poverty has been reduced. In the *World Atlas of Biodiversity*, published by UNEP in 2003, the number of extinctions of fish, birds, and mammals in the last third of the 20th century was only one half that in the last third of the 19th century, and no greater than the rate of extinctions in the 16th century. D. Avery of the Hudson Institute noted that more investment in agricultural R&D is needed to ensure that the global rate of species extinction continues to decline in a more populous and affluent 21st century. His regular pithy reports make thought-provoking excellent reading.

GEF International accord on increasing the funding of the Global Environment Facility (GEF) from $2.2 billion to $3.2 billion over four years to encompass a wider remit was stymied by the USA, which regarded with some justification monitoring of the spend to be inadequate. Established in 1992, the Facility funds the UN Conventions on Biological Diversity and Climate Change.

Kyoto Protocol At the end of May 2002, representatives from all the EU governments and the European Commission formally ratified the Kyoto Protocol. The following month, however, Australia refused to sign the Protocol on the basis that it would be economically disadvantageous. Russia indicated that it would sign up but did not set a date, and China announced that it had ratified the Protocol although as an LDC, it was not obliged to do so. The USA refused to ratify the Protocol but introduced in early 2002 a system of tax breaks to encourage industry to reduce greenhouse-gas emissions, in addition to increased research spending. Despite publicly announced commitments on emissions controls, the International Energy Agency stated in a report in September 2002 on the world energy outlook, that the OECD countries would fail to meet their Kyoto targets for carbon dioxide reduction even if the promised policies were fully implemented. OECD aggregate emissions would only stabilise by 2030 at the earliest as opposed to falling by 5.2% between 2008 and 2012. The rôles and interrelationships of greenhouse gases, high-level and low-level clouds, solar activity, solar wind, cosmic rays, oceans and seas, forests and forest clearance, agriculture, volcanoes, dust clouds, black carbon soot from the combustion of fossil fuels (especially diesel) and agricultural wastes, *etc*. entertained activist groups and research scientists alike, not least in respect of the reasons for the heating and cooling cycles during Earth's history, as well as predicting the environmental effects of attempts to change atmospheric gaseous composition. There was less debate about the potential effects of global warming. In refusing to sign up to the Protocol which it regarded as an unrealistic and ever-tightening straitjacket, the USA administration pointed out that it spends *circa* $1.75 billion *per annum* on global-climate-change R&D, is active in the UN framework convention on climate change, and launched both the International Partnership for a Hydrogen Economy and the Carbon Sequestration Leadership Forum. Within the USA, individual states and companies started to implement stringent policies to reduce CO_2 emissions.

Sequestration A successful carbon sequestration experiment was reported in September 2002. Since 1996, around 5 million tonnes of carbon dioxide separated from methane extracted from the Sleipner Field in the North Sea was pumped as a fluid into a porous sandstone reservoir. Elsewhere, an international consortium withdrew its application to inject 60 tonnes of liquefied carbon dioxide into the deep ocean off the coast of Hawaii, following vigorous opposition from environmentalists. An attempt to transfer the experiment to a site off the Norway coast was abandoned after the Norwegian pollution-control agency rescinded the licence for the work to go ahead. Interest in 2002-2003 was renewed in the massive gas deposits in the form of sea-floor hydrates formed around continental margins, not only because of their potential as a source of energy, as pointed out in the original UK Technology Foresight Programme, but their potential to modify the global climate were they to be released catastrophically. The commonest gas hydrate contains the greenhouse-gas methane.

Atmospheric Pollution The most pronounced event of atmospheric pollution ever was revealed by observations from the Indian Ocean Experiment. A three-kilometre-high unhealthy brown haze covered much of southern Asia, and a similar haze covered parts of south-eastern and eastern Asia. The haze was created by a combination of persistent forest fires (often related to illegal forestry and slash-and-burn agriculture) and burning of agricultural wastes as well as the combustion of wood, cow dung and fossil fuels for cooking, heating and energy. According to research by Johns Hopkins University Baltimore, USA, and Health Canada, Ottawa, the standard statistical software used to estimate the health risks from very small soot particles had overestimated by 20-50% the reputed risks.

Wastes All societies are challenged by the need to control, store, or eliminate toxic wastes, in addition to handling and containing normal industrial and domestic wastes. Contaminated land, water, and atmosphere are the targets of remediation programmes and experimentation in nearly all MDCs. Most LDCs are unable to regulate the handling of toxic wastes, a situation made worse when recycling or storage services are offered at lower cost than in the MDCs. Examples of severe contamination events were recorded in villages on the outskirts of Guiyu in China, where recycling of electronic waste took place, and also in the port of Djibouti where large-scale leakage of chromated copper arsenate led to a recommendation from the FAO that the chemical waste be cleaned up and returned to its country of origin, the UK. Wastes from the nuclear industry and radioactive wastes from hospitals and laboratories represent a conumdrum for policy makers that appreciate the Kyoto-efficiency of nuclear energy generation and the health and experimental benefits of radiotherapy, imaging, and experimental tracers, but baulk at the social, economic, and political costs and risks of waste storage, an undesirable heritage, almost invariably for periods that extend for generations into the future. The proposed storage facility at Yucca Mountain, Nevada, USA, due to open in 2010, was planned to hold about 77,000 tonnes of waste that would remain in the facility for 10,000 years. Similar to the position in the UK, the local authorities and environmental pressure groups continued to resist the planning of such developments.

Chemical Industries Estimated to have an annual global turnover of around $1,700 billion, the chemical industry was under strain in both the EU (the world's largest chemicals exporter) and the USA. Depressed commodity chemical prices, insufficient margins in the emerging speciality chemicals sector, a euro-zone industry initially protected by a weak euro being placed under greater import pressures, US producers subject to high gas prices, and a series of mergers and acquisitions collectively led to instability in the industry during 2002-2003. In contrast, the chemicals industry expanded in the Middle East and Asia. Ready availability of low-cost oil and gas in the Gulf led to regional expansion of the petrochemical industry, notably in plastics. The region was forecast to dominate global steam-cracker ethylene projects, with ethylene (ethane) production in 2003 treble that of 1990, and set to double again by 2010. Ethylene is a valuable feedstock for conversion into polyolefins. Most of the expansion will be in the Arab Emirates, Iran, Kuwait, Qatar, and Saudi Arabia.

Massive investment and expansion of the chemicals industry in China and India placed further pressure on European and US companies. Demand in Europe and Japan remained muted, at a time when there was the emergence of Asian speciality chemical producers and growing local and foreign investments in R&D. Over the past two years, China emerged as the world's largest petrochemical importer as well as the largest manufacturing, commodity chemicals, and white-goods exporter. According to Sinodata, in 2001, China exported more than 50% of the 40.9 million telephones, 210 million electric fans, and 40.9 million colour televisions it manufactured, and more than 40% of the 84 million vacuum cleaners, 13.5 million refrigerators, and 80 million personal-computer monitors it manufactured. Similarly, China became a major force in the global textile and clothing industry, becoming in 2002 the leading supplier to the USA.

European and US companies sought to become knowledge-based rather than physical-asset-based, by investing in R&D to become innovative, protected by patents, and moving into 'regulated' areas of activity that have high market-entry conditions, notably agrochemicals. Most of the agrochemical industry has less generic competition than the pharmaceutical industry, even though both industries have onerous approval processes. Agrochemicals form one part of the chemical industries that is highly consolidated with EBITDA (earnings before interest, and tax) margins typically around 15-25%, aided by the protection afforded by heavyweight environmental regulation and in Europe by the EU's illegal moratorium on GM crops which has almost eliminated competition from US companies. Investments in pharmaceutical manufacturing accompanied by costs of statutory inspections and quality-assurance schemes did not realise expected rewards, a position stressed further by declining productivity of the major pharmaceutical companies. Some companies regarded increased environmental and health regulation as a route to opening up new markets and competitive advantages. Reductions in the use of volatile organic solvents led to the creation of a new generation of water-based paints; in the same vein, vehicle-emission controls led to the auto-catalysis market and new types of fuel, stimulating for example renewed interest in hydrogen fuel cells and novel methods of hydrogen production (*e.g.* from algae and from waste waters).

As the European Commission took forward through 2002 and 2003 the new European chemicals policy entitled REACH (Registration, Evaluation, Authorisation and Restrictions of Chemicals in the Commission White Paper, 27 February 2001 on the strategy for a future chemicals policy, COM(2001)88), aimed at replacing current legislation and placing the burden of proof for the safety of chemicals on companies that produce, import, or use chemicals, it was reckoned by some that the total cost for industry and downstream users would be €2.3-5.2 billion whereas the anticipated benefits to human health and the environment over 30 years would be ten times greater than that cost. Industry groups, however, sought a proper cost-benefit analysis, and expressed concern over the impacts of the legislation on employment in the EU, investments, generation of intellectual property, profitability, international competitiveness, and a change in the balance of imports and exports. Environmental and other pressure groups – civil society groups – sought much tougher controls.

Royal Commission on Environmental Pollution A study of the long-term effects of chemicals on the natural environment and on humans led the Royal Commission on Environmental Pollution (Twenty-fourth Report, *Chemicals in Products – Safeguarding the Environment and Human Health*, June 2003. TSO, ISBN O-10-158272-2, Cm5827) to offer 54 recommendations on addressing the problems of dealing with the current fragmented assessment and regulatory processes throughout the world. Major doubts exist about the effectiveness of present policies to protect the health of ecosystems and humans from unintended long-term effects. The study dealt with 'synthetic' chemicals – those manufactured by industry regardless of whether or not they occur in nature – as well as naturally occurring chemicals that have been extracted and concentrated by industry. Depending on the definition used, it was estimated that there are between 30,000 and 100,000 chemicals on the market in greater than laboratory-scale quantities, with several hundred new substances added every year. Less than 5% fall into categories that are approved for specific uses such as pesticides, biocides, pharmaceuticals, or food additives. Few of the chemicals have been subject to risk assessments, and there are nonetheless limitations and uncertainties in the various hazard-evaluation processes, let alone proper cost-benefit analyses. Yet another component in the risk-management strategy is that different interests, beliefs, and what was termed 'people's values' should be considered. The Commission, *inter alia* recommended that (a) a system of chemicals assessment and monitoring should comprise four steps of listing marketed chemicals, sorting to select chemicals of concern, evaluation of selected chemicals (into high, medium, low or no concern), followed by risk-management action. (b) Where synthetic chemicals are found in elevated concentration in biological fluids such as breast milk, they should be immediately removed from the market. (c) All practicable steps should be used to avoid the use of higher animals as test organisms. (d) A chemicals safety co-ordination unit should be placed in the Environment Agency in order to provide a coherent and integrated national chemicals management programme to underpin regulation and administration. (e) Environmental monitoring including epidemiological studies should be expanded and linked with the chemicals safety co-ordination unit. (f) Substitution of hazardous substances with others of lower hazard should be a central objective of the chemicals policy, and can be achieved by the design, manufacture, and deployment of environmentally benign chemical products and processes ('green chemistry) as well as 'white biotechnology' or by substitution with non-chemical processes, thereby providing environmentally sustainable products. (g) Random tests should be carried out on the composition of chemical products, including imported products. (h) To drive the necessary changes, the Government should introduce a charging scheme to stimulate greater substitution of hazardous chemicals, and wholesalers, retailers, and manufacturers should be jointly and severally liable under the Consumer Protection Act. (i) The Government should review the rôle of commercial confidentiality and statutory protection of relevant intellectual property rights, an area, as the aspect of legal liability, difficult to police and enforce across international boundaries. (j) Interestingly, besides encouraging the use of advanced methods for searching the literature and databases, and for mass-screening of chemicals combined with predictive physiological techniques, the Commission recommended a study to anticipate the challenges to traditional civil liability concepts posed by increasing knowledge of genetic susceptibilities to specific chemicals. Overall, it was that that the aim of the recommendations ensure that within a few years all chemicals in use in society have been listed and screened for their hazardous potential, and that the risks they pose are being systematically reduced.

Habitat Conservation Conservation virtually ceases in war-torn regions. Wildlife invariably suffers as habitats are destroyed in the hunt for terrorists, enemy forces, or for food (principally bushmeat) and shelter. When combined with drought, as in Afghanistan, the scale of the environmental catastrophe was soon evident. An 85% decrease was recorded in 2002 in the number of birds crossing eastern Afghanistan, one of the world's most important migratory routes. The Great Lakes region of Africa suffered devastation of most of its major habitats. Elsewhere, in more politically stable LDCs, illegal logging and slash-and-burn agriculture reduced further the areas of land classified as natural habitats. There were projections that the Tesso Nilo forest in Sumatra, identified by the World Wildlife Fund as the world's richest lowland forest in biological terms, would be completely destroyed by 2005 by illegal logging.

Intervention to defend the natural flora and fauna against aggressive 'alien' plants and animals has been argued to be justified by the UK Department for Environment, Food and Rural Affairs (Defra) to avoid economic, cultural, and spiritual loss, and would increase diversity and preserve local distinctiveness in the widely diverse habitats of the UK. Eradication of non-native species, however, can be a major undertaking, with an estimate of $1.6 billion just to eradicate the aggressive introduced Japanese knotweed from the UK. A situation of massive gene flow driven by globalisation expressed through the international movement of goods, people, livestock, and plants, together with hitch-hiking pests and diseases, is amplified by weak quarantine measures, the spontaneous appearance of new genetic variants, and changing climates. The latter point is especially relevant, as current indications are towards movement of species to higher latitudes, the shifting of seasons, and 'green-bridging' whereby species are able to overwinter when hitherto they would have been eradicated naturally by low temperatures. Certain invading species (rarely cultivated species) have the capacity, and have demonstrated their ability, to dominate habitats and interbreed with native species. Under the auspices of the Convention on Biological Diversity, national governments have a duty to prevent the spread of undesirable alien species.

Modern thinking on conservation has evolved from sustaining the *status quo*, the static habitat concept, to formal recognition of the fact that gene flow occurs naturally in all habitats. Diverse views on the degree of exaggeration of the impacts of alien species, philosophical concerns over eugenic attitudes to unwanted species and animal-rights issues, and the sheer practicalities of preserving habitats, nonetheless have to confront the challenges of eliminating unwanted invaders, such as pests, diseases, and weeds (especially garden escapes). To date, the most effective approaches have been culling and agrochemicals, with biological control systems still in their infancy. The soil remains largely scientifically underexplored territory.

UK Perspectives

Financial Reporting Accounting and financial-reporting standards remain at the heart of governance of both public- and private sector organisations (see *Accounting and Auditing Standards. A Public Services Perspective*. The Chartered Institute of Public Finance and Accountancy, 2003). A note of caution, though, for life scientists and those in their ranks that aspire to lead research groups or even research institutes – never lose sight of the primary objective to deliver scientific discoveries, inventions, and concepts in one of the most exciting and fast-moving areas of scholarship, notwithstanding bureaucratic essentials. *Sydney Brenner. A Life in Science* (As told to Lewis Wolpert. Edited interview with additional material by E. C. Friedberg and E. Lawrence, BioMed Central Ltd/. 2001 ISBN O-9540278-0-9), should be obligatory reading for those controlling science. In the UK, the responsibility for setting accounting standards resides with the Accounting Standards Board (ASB), a subsidiary of the Financial Reporting Council. The ASB issues its pronouncements in the form of financial reporting standards (FRSs), as well as adopting statements of standard accounting practice (SSAPs) issued by the predecessor body of the ASB, the Accounting

Standards Committee. In 2002, the ASB announced its intention to align UK accounting standards with international accounting standards wherever practicable. The ASB has a rôle in the development and issue of statements of recommended practice (SORPs) for specific specialised areas such as parts of the public sector and the financial sector. There is a likelihood that the remit of the Financial Reporting Council will be extended to audit and the Auditing Practices Board. For the central government sector (government departments, executive agencies, trading funds, and non-departmental public bodies – NDPBs) responsibility for determining accounting and financial reporting requirements lies with the Scottish Executive in Scotland, and the Treasury in England and Wales. For NDPBs and like bodies (SCRI was an NDPB until April 2003), this responsibility is derived indirectly through the requirement for accounts directions to be issued by individual sponsoring departments (such as the Scottish Executive Environment and Rural Affairs Department) with Treasury approval. The main source of guidance is the *Resource Accounting Manual* which sets common standards consistent with UK generally accepted accounting practice (GAAP) to the extent that it is meaningful and appropriate in the public-sector context. Further and higher education institutions represent a specialist grouping that focus on teaching and research but they vary greatly in their size, complexity, background, basis of establishment, resource base, and pension costs. The SORP *Accounting for Further and Higher Education* issued for 1999-2000 was under review in 2002-2003.

Supported by the *Resource Accounting Manual,* processes are in place for the introduction of consolidated financial statements covering the whole of the UK public sector, to be audited and based on UK GAAP – the Whole of Government Accounts (WGA). Australia and New Zealand successfully introduced WGA several years ago, and other countries have stated their intention to produce WGA.

In 2001, the International Accounting Standards Committee (IASC) gave way to the International Accounting Standards Board (IASB) as the major vehicle to develop and issue what were IASC International Accounting Standards, now referred to as IASB International Financial Reporting Standards. The IASB is governed and monitored by the trustees of the IASC Foundation, itself intended to be representative of the global capital markets, and is assisted by the International Financial Reporting Interpretations Committee and the Standards Advisory Council. From 2005 at the latest, all EU companies listed on the regulated market will be required to produce consolidated accounts according to International Accounting Standards/International Financial Reporting Standards. A European Financial Reporting Advisory Group has been established to contribute to the work of the IASB in Europe.

Reinforcing the IASB and accountancy generally is the International Federation of Accountants comprising 156 member bodies in 114 countries. It has several boards and committees, one of which, the International Auditing and Assurance Standards Board, is responsible for the development and issue of international standards on auditing. The IFAC Public Sector Committee, is responsible for the development and issue of international public-sector accounting standards (IPSASs) which aim to deliver consistent financial reporting by governments and their sub-sets, using both cash and accrual bases of accounting. The UK has not agreed to adopt IPSASs or to harmonise with them, but has stated its intention to keep them under close review. In addition to IFAC, there is the Fédération des Experts Compatbles Européens that represents 38 professional bodies from 26 European countries, including all the 15 EU Member States and the three main member countries of the European Free Trade Association.

For public-sector groups worldwide, there are challenges about (a) the nature of the accounting principles to be applied and their relationship to the private sector; (b) differential treatment of accounts, with no generally agreed way to demonstrate proper stewardship of public funds; (c) problems over accounting for cost of capital, current value and depreciation, infrastructure assets, pension liabilities, private finance initiatives, non-exchange revenues and social policy obligations, and heritage assets. Coincidently, the IASB recently published proposals requiring companies to identify and value separately newly acquired intangible assets such as patents, databases, and trade secrets, rather than aggregating these with goodwill or its equivalent. For R&D-based or brand-based organisations this will present considerable difficulties.

Auditing standards in the Republic of Ireland and the UK are derived from the Auditing Practices Board (APB), formerly a subsidiary of the Financial Reporting Council in 2003. The APB issues statements of auditing standards (SASs) relating to the conduct of audits of financial statements, practice notes, bulletins, and consultative papers. The peculiarities of the public sector are considered by the APB's Public Sector Sub-Committee as well as by the Public Audit Forum, established in 1998 by the four UK audit agencies (National Audit Office, the Northern Ireland Audit Office, the Audit Commission, and the Accounts Commission for Scotland). In Scotland, audits in the public sector are overseen by the Accounts Commission for Scotland, the Auditor General for Scotland, and Audit Scotland.

Consistency in auditing practices and related services worldwide is driven by an IFAC Committee – the International Auditing and Assurance Standards Board (IAASB), and is the main body for the issuance of international standards on auditing (ISAs) and international auditing practice statements (IAPSs). National or government audit offices of over 170 countries belonging to the UN have come together to form the International Organisation of Supreme Audit Institutions (INTOSAs), founded in 1953, and having a conceptual framework in *The Lima Declaration of Guidelines on Auditing Precepts*. For the UK, the National Audit Office is a member of INTOSAI. At this juncture, INTOSAI auditing standards do not have mandatory application. In the UK, the nature and scope of audit throughout the public sector varies in the way in which the substantive topics are dealt with, *viz*. financial statements, value for money, regularity and legality, internal controls, proper conduct including quality and extent of corporate governance, performance indicators, and financial standing. Much hinges on the auditor's opinion and the 'true and fair' argument. Unfortunately, there is no universally accepted definition of the term 'true and fair' despite the fact that in the UK the requirement that all financial statements should "give a 'true and fair' view" was first introduced in the Companies Act 1947, and subsequently incorporated into the EC 4th Company Law Directive, and the first statutory recognition of accounting standards was in the Companies Act 1989. The IASB *Framework for the Pr4eparation of Financial Statements* uses the phrases 'true and fair view' and 'fair presentation' as one and the same, but does not analyse these concepts. Clearly, a consensus view will be needed before WGA can become universal, and proper reassurance of accounts and auditing standards will underpin the capital markets.

Corporate Governance Based on the *Review of the Rôle and Effectiveness of Non-Executive Directors* (the Higgs Report published in January 2003), and the review on *Audit committees: Combined Code Guidance* (the Smith Report published in January 2003), the *Combined Code on Corporate Governance* was issued by the Financial Services Agency in July 2003, replacing the *Combined Code* issued in June 1998 by the Hampel Committee on Corporate Governance. It was intended that the new Code will apply for reporting years beginning on or after 1 November 2003. The Code's principles and provisions are to be complied with unless a considered explanation is formally given to justify any departure from its specific provisions *e.g.* disproportionately onerous largely irrelevant provisions relating to smaller, listed companies. Guidance is given on how to comply with specific parts of the Code, relating not only to the Smith Report but also to *Internal Control: Guidance for Directors on the Combined Code* produced in September 1999 by the Turnbull Committee for the Institute of Chartered Accountants in England and Wales. Supplementing the new Code are *The Directors' Remuneration Report Regulations 2002*, S. I. no. 1986. Of particular relevance to both public- and private-sector organisations are the main principles enunciated in the Code of Best Practice in the Code. These are as follows. (a) Every company should be headed by an effective board, which is collectively responsible for the success of the company. (b) There should be a clear division of responsibilities at the head of the company between the running of the board and the executive responsibility for the running of the company's business. No one individual should have unfettered powers of decision. (c) The board should include a balance of executive and non-executive directors (and, in particular, independent non-executive directors) such that no individual or small group of individuals can dominate the board's decision-making. (d) There should be a formal, rigorous, and transparent procedure for the appointment of new directors to the board. (e) The board should be supplied in a timely manner with information in a form and of a quality appropriate to enable it to discharge its duties. All directors should receive induction on joining the board and should regularly update and refresh their skills and knowledge. (f) The board should undertake a formal and rigorous annual evaluation of its own performance and that of its committees and individual directors. (g) All directors should be submitted for re-election at regular intervals, subject to continued satisfactory performance. The board should ensure planned and progressive refreshing of the board. (h) Levels of remuneration should be sufficient to attract, retain and motivate directors of the quality required to run the company successfully, but a company should avoid paying more than is necessary for this purpose. A significant proportion of executive directors' remuneration should be structured so as to link rewards to corporate and individual performance. (i) There should be a formal and transparent procedure for developing policy on executive remuneration and for fixing the remuneration packages of individual directors. No director should be involved in deciding his or her own remuneration. (j) The board should present a balanced and understandable assessment of the company's position and prospects. (k) The board should maintain a sound system of internal control to safeguard shareholders' investment and the company's assets. (l) The board should establish formal and transparent arrangements for considering how they should apply the financial reporting and internal control principles and for maintaining an appropriate relationship with the company's auditors. (m) There should be a dialogue with shareholders based on the mutual understanding of objectives. The board as a whole has responsibility for ensuring that a satisfactory dialogue with shareholders takes place (notwithstanding the general requirements of law to treat shareholders equally in access to information). (n) Institutional shareholders should enter into a dialogue with companies based on the mutual understanding of objectives. (o) When evaluating companies' governance arrangements, particularly those relating to board structure and composition, institutional shareholders should give due weight to all relevant factors drawn to their attention. (p) Finally, institutional shareholders have a responsibility to make considered use of their votes.

Three schedules in the *Combined Code* are central to running of modern companies. Schedule A concerns the provisions on the design of performance-related remuneration and the operation of a remuneration committee. Schedule B gives guidance on liability of non-executive directors, referring to care, skill, and diligence, and what may reasonably be expected of a non-executive director given that the time devoted to a company's affairs are likely to be considerably less than that of an executive director. Schedule C relates to formal disclosure of corporate-governance arrangements, noting that the Annual Report (*i.e.* the report lodged with Companies House) should record a statement of how the board operates, names of key individuals, number of meetings of the board and committees and details of individual attendance, other significant commitments of the chairman, details of board performance evaluation, processes the board has undertaken to understand the views of the major shareholders, the look of the nomination audit and remuneration committees, details of responsibilities for preparing the accounts and statements from the auditors, a statement from the directors that the business is 'a going concern', a report that the board has conducted a review of the system of internal controls, any deviation from the audit committee's recommendation on the external auditor, and an explanation of how – if the auditor provides non-audit services – auditor objectivity and independence is safeguarded.

Particular interest has been directed towards the suggestions for good company practice from the Higgs report. These suggestions cover (a) guidance on the rôle and responsibility of the chairman, noting the characteristics required to be effective; (b) guidance on the rôle of the non-executive director, which in addition to the usual rôles expected of directors, encompass special attention to strategy, management performance, risk analysis and management, and key people in the company; (c) a summary of the principal duties of the remuneration committee and the nomination committee; (d) pre-appointment due-diligence checklist for new board members, (e) a sample letter of non-executive director appointments; guidance on the induction of new board members, covering the synthesis of an understanding of the nature of the company, its business, and the markets in which it operates, as well as building links with the staff of the company; and (f) guidance on performance evaluation of the board collectively, of the chairman, of non-executive directors, and consequently of the relationship of the board with the executive.

R&D Innovation is regarded as central to the sustainability of industry, creating high-value products, processes, and services, as well as generating highly paid employment and a firm taxation base. It is the engine of sustainable competitiveness. Research and development (R&D) are the essence of innovation, although R&D should not be thought as entirely laboratory-centred, nor linear in progress from basic research, through to strategic research, applied research, and then development. Rather, the system is three-dimensional and strongly interactive, as for example, technological developments are fundamental to progress in basic research, and the outputs of basic research can come quickly to market.

Government funds the UK public-sector science and engineering base in the universities, colleges, and research institutes, supporting research grants, studentships, and facilities. Currently, financial support for non-university public research sector is around £1.6 billion *per annum*, directed at the so-called 'public-sector research establishments' consisting of Research Council institutes and Government Department research establishments of various types, including the Scottish Agricultural and Biological Research Institutes. Further financial support comes from the European Union, particularly the EC Framework Programme (at levels well below full economic cost), and also to a limited extent from charities and from the private sector. Rarely are there donations! Government also assists R&D by introducing R&D tax credits, and by trying with limited success as a result of ingrained suspicions about the private sector to ensure effective, market-measurable, knowledge and technology transfer.

UK R&D Scoreboard Verification of the view that companies with above-average R&D spend in the longer term tend to show above-average sales-growth, productivity, and market value or shareholder return, has been given in the annual *R&D Scoreboard* published by the Department of Trade and Industry. This series, the latest being the *2003 R&D Scoreboard*, is one of the most useful international benchmarking tools for UK companies to compare their R&D and capital expenditure portfolios with the best international competitors. In the *2003 R&D Scoreboard*, details of the top 500 UK companies by R&D investment together with details of the top 700 R&D-active companies were presented, giving R&D investments, capital expenditure, sales, profits, employee numbers, as extracted from company annual reports and accounts. Also included for the first time was information on cost of funds, US patents, and market-capitalisation-to-sales ratios. The top 700 UK companies were listed under 32 sectors, and the top 700 international companies under 27 sectors. R&D was based on the OECD 'Frascati' manual, commented on in my previous reports, and defined in SSAP13 (Standard Statement of Accounting Practice) and IAS38 (International Accounting Standard). As the report stressed, R&D as reported is not the sole or complete measure of investment because market development, training, capital equipment, and certain intangible assets can all provide innovative ways of gaining competitive advantage. Nor does the report cover all R&D activity in the private sector, or companies spending less than £30,000 *per annum* on R&D. The five high R&D sectors were electronic & electrical, health, information technology (IT) hardware, pharmaceuticals & biotechnology, and software & IT services, all of which accounted for almost 60% of international 700 R&D, and with the exception of electronic & electrical were dominated by the USA.

Considering the business environment was difficult during 2002-2003 with depressed profits and a decrease in the number of employees, R&D intensities (R&D as a percentage of sales) nonetheless were unchanged from 2002 for Japan at 4.3%, increased to 5.2% in the USA and to 3.7% in Europe. Within Europe, both Germany (4.6%) and Switzerland (6%) increased their intensities whereas the UK R&D intensity changed only marginally remaining at around 2.2%.

As a result of the higher dividends paid by UK companies, they had a higher cost of funds relative to both sales and R&D (over 200%) compared with France, Germany, Japan, and the USA (an international average of 90%). Another characteristic of the UK business environment, commented on in my previous report, was the fact that acquisition spend relative to R&D plus capital expenditure is substantially higher than even in the USA. A total of 684 acquisitions were made by 97 UK companies in 8 sectors over the period 1997-2001. The top 30 UK companies accounted for three quarters of all acquisition expenditure and 21 of these companies under-performed the FTSE all-share index after making their largest acquisition, severely so in many instances. They failed to grow based on their endogenous innovation. In the USA, 665 companies completed only 1931 acquisitions, giving rise to the situation that the UK was in 2002-2003 in a more advanced state of consolidation than the USA.

Analysis of the data shows that the UK had its highest proportions of R&D in pharmaceuticals & biotechnology (40%) and aerospace & defence (9%), compared with the international 700 companies which had the highest proportions in IT hardware (22%), automotive (18%), and pharmaceuticals & biotechnology (17.5%). Although not stated, global agribusiness is second only to pharmaceuticals & biotechnology in R&D spend as a percentage of sales. The UK 700 R&D intensity was above international levels in pharmaceuticals, aerospace, and health but generally below in other sectors. The scale of the challenge facing UK companies is revealed by the fact that a comparison of the US 1000 with directly comparable UK-owned companies in the UK 700 showed that the UK has 50% more companies with an R&D intensity below 2%, but only just over one third the proportion of companies with a high R&D intensity of over 10%. Even so, the relative position of the UK improved over the last four years. Though it is not generally recognised, the UK is relatively strong internationally in food processing.

One measure of competitive advantage is the possession of intellectual property protected by patents, notably those taken out in the leading global market, the USA. Clearly there are limitations to interpreting comparisons of numbers of patents, patent citations, and values attached to patents, but the costs of patents as revealed by company accounts (there may have been other costs as, for example, unaccounted preliminary work carried out in the public sector), were analysed as the average number of US patents granted in 2002 *per* £10 million R&D investment for 150 large R&D companies from 10 sectors. For pharmaceuticals and biotechnology, there was remarkable similarity across Europe, Japan, and the USA of only one patent *per* £10 million R&D spend, presumably to meet the costs of gaining regulatory approval. Reports throughout the year commented on the declining efficiency of the sector to generate valuable intellectual property, perhaps a harbinger of a harsher investment climate. Around 6-7 patents *per* £10 million were generated in the electronic & electrical and IT hardware sectors, around 6 in personal care, and around 4-5 in automotive components and chemicals.

UK companies by and large performed poorly overall compared with their international peers, possibly as a result of the absence of long-established taxation regimes supportive of R&D investments, the current relief system being established as recently as 2000. Stated problems about the lack of R&D spend include the subjective nature of the official guidance on those activities recognised as R&D, the obstructive attitude and lack of technical knowledge of the Inland Revenue officials, and the restriction of relief just to revenue costs in the profit-and-loss account.

Public-Sector R&D A measure of the global positioning of the UK public-sector R&D effort was issued in 2003 by the Office of Science and Technology (OST), a sub-set of the DTI responsible also for the UK Research Councils, using a group of performance indicators developed by the consultancy Evidence. It was stated that the UK ranked thirteenth of 17 nations of the OST comparator group for which data are available on the R&D spend as a proportion of GDP. Those of us in the UK public sector actively seeking private-sector funding appreciated that the UK in this regard was about twice as effective as the average from the comparator group. The UK is third, after the USA and Japan, in publishing papers in international journals, second to the USA in world citations, and second to the USA in all disciplines except mathematics (third) and engineering and physical sciences (fourth). The biological, environmental, and physical sciences were particularly effective. Germane to the debates about quality, the UK publishes fewer uncited papers than its international competitors, produces a large number of PhDs relative to higher-education spend, and science productivity (number of publications and citations *per* researcher) is only behind that of Switzerland and The Netherlands. In contrast, the UK is particularly weak in respect of the availability of highly skilled personnel with research training (see www.ost.gov.uk/policy/psa_target_metrics.htm). What is desperately required is an assessment of the effectiveness, efficiency, and sustainability of the strategic and applied science base of the UK, based not on simplistic quality-of-science judgements but on outputs and outcomes.

UK Government policies aim to strengthen the science and engineering base, which covers both the university sector and a group of more than 60 Research Council institutes and Government Department or Government-sponsored research establishments (see *Investing in Innovation: A Strategy for Science, Engineering and Technology*. HM Treasury, Department of Trade and Industry, and Department for Education and Skills. July 2002). During the year, concerns were expressed about the sustainability and strategic coherence of the non-university public research sector, particularly with respect to ownership, responsibilities, tasking, full economic costing, funding, and contracting.

UK Environment See also section on **UK Agriculture** **Environmental Legislation** Protection of the environment in the UK comes from a combination of legislation and strategies arising from the need to meet the cacophony of requirements of (a) over 50 international conventions and protocols; (b) over 300 existing European Directives and others in preparation; and (c) guidance and imperatives of government, national and developed administrations. Regulation is applied through the Environment Agency, the Scottish Environment Protection Agency, and the Environment and Heritage Service for Northern

Ireland. Also involved are individuals, local authorities, voluntary and charitable bodies including NGOs, companies, scientific societies and pressure groups. In the context of the EU, the EC's Sixth Environmental Action Programme, *Environment 2010: Our Future, Our Choice*, adopted in 2001, sets the action programme to 2010, focusing on (a) implementation of existing legislation, (b) integrating environmental issues into other relevant policies, especially land-use planning and management decisions, (c) involving the private sector, and (d) engaging with private citizens. Four topics are prioritised: climate change, biodiversity, environment and health, and natural resources and waste.

Sustainable development, sustainability (however defined), and the so-called 'environment agenda' inculcate governmental and business policies. *A Better Quality of Life*, published in May 1999, is the latest UK strategy on sustainable development, and contains 15 headline indicators plus 150 other indicators to measure sustainability. By March 2002, the Government released the second annual progress report on sustainable development, noting that 10 of the 15 headline indicators showed movement in the 'right' direction. In April 2002, the Scottish Executive issued a statement on sustainable development, followed at the end of the year by quantitative estimates of 24 indicators. Driven by Local Agenda 21 which arose from the 1992 UN Conference on Environment and Development in Rio de Janeiro, local authorities are obliged to draw up sustainable development strategies.

Without the application of new technologies, sustainable waste management is an oxymoronic term, but at least four appropriate principles underpin government policy, driven in large measure by EU Directives: (a) the waste hierarchy of reduce, reuse, recycle, dispose; (b) the proximity principle of disposing of waste close to its site of generation; (c) national self-sufficiency; and (d) 'the polluter pays' concept. Manufacturing industry in the EU is likely to be reconfigured if it survives global competition by the proposed EU integrated products policy which is designed to internalise the environmental costs of products throughout their life-cycle, using market forces driven by legislation. This will mean (a) enhanced emphasis on eco-design and life-cycle assessments, (b) incentives to purchase 'greener' products and (c) renewed focus on the producer responsibility directives for packaging wastes that came into force in the UK in 1997, giving greater responsibility for end-of-life products, perhaps best exemplified by the end-of-life vehicle directive which came into force in December 2001, and the proposed batch of directives on waste electronic and electrical equipment, and restricting or eliminating the use of certain hazardous substances in this equipment.

Ratification of the Framework Convention on Climate Change by the UK took place in December 1993, and came into force in March 1994. It led to a series of commitments by all the signatories to reduce the risks of global warming arising from the emissions of a range of 'greenhouse' gases. A protocol to the Convention was adopted in 1997 in Kyoto to cover the six main greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride), with MDC signatories agreeing to cut their emissions of greenhouse gases by 5.2% below 1990 levels by 2008-2012, but EU members voluntarily agreed to a tougher 8% reduction, with the exception of the UK which volunteered a 12.5% cut at a time when there was a phasing out of coal-burning power stations. From the Protocol arose three approaches – the Kyoto mechanisms – to provide flexibility and reducing the costs of meeting the targets *viz.* (a) the clean development mechanism, (b) emissions trading, and (c) joint implementation. The international rules and operational details of the Kyoto Protocol were agreed at the seventh Conference of the Parties held in Marrakech, Morocco, in November 2001. The UK's climate change programme launched in November 2000 incorporated the essence of the Kyoto Protocol agreements and issued policies and targets in meeting its aspiration specifically of a 20% reduction in carbon dioxide emissions by 2010. Thus, (a) a climate change levy was introduced in 2002, applying to the sales of electricity, natural gas, liquefied petroleum gas, and coal, to both the business and public sectors; (b) energy efficiency standards applied to electricity and gas suppliers to encourage improved energy efficiencies by domestic consumers; (c) agreements (enforcements) with energy-intensive sectors of industry to reduce consumption; (d) integrated pollution prevention and control; (e) improved energy management of public buildings – sadly ignored hitherto in my experience in the design and construction of buildings in the UK public sector; (f) cuts in the use of fertilisers; and (g) emissions trading. With regard to the latter, a voluntary greenhouse-gas emissions trading scheme started in April 2002 whereby participating companies and organisations make emissions reductions in exchange for incentive payments. From a competitive auction in March 2002, 34 companies took on legally binding emission reductions. Within the EU, a mandatory carbon-dioxide emissions trading scheme for companies was proposed to begin in 2006, in which national governments impose total carbon dioxide caps on companies which they would then be able to trade for carbon-dioxide allowances within the EU – the so-called 'cap and trade' scheme. Changes in the sourcing of energy in the UK will inevitably occur as the oil and gas reserves in the North Sea decline. The 'carrot and stick' approach to meeting the Kyoto obligations – caps on greenhouse-gas emissions and encouragement to invest in 'green-energy' (renewable-energy) schemes raised questions about future energy costs and the competitive position of UK industry. Heavy costs were predicted for the construction of dispersed renewable-energy-generating systems and connecting them to the national grid.

Air pollution controls that extend beyond the Framework Convention on Climate Change include (a) the Convention on Long Range Transboundary Air Pollution which came into force in 1993 and comprising protocols covering several specific pollutants, and (b) the European Integrated Pollution Prevention and Control Directive (based on the UK Environmental Protection Act 1990) which came into force in August – September 2000 and implemented in the UK through the Pollution Prevention and Control regulations 2000. These latter regulations also implement in part the EC Solvent Emissions Directive aimed at ameliorating the effects of volatile organic compounds. A revision took place in January 2000 of the UK National Air Quality Strategy published originally in 1997, and setting targets to be met during 2003-2008 for the eight major types of air pollutant: benzene, 1-3 butadiene, carbon monoxide, lead, nitrogen dioxide, ozone, particulates, and sulphur dioxide. Local authorities bear the brunt of meeting the objectives of the Strategy. In future, targets for polycyclic aromatic hydrocarbons will be incorporated in the Strategy, following new EU guidelines.

Water Of special relevance to agriculture and horticulture was the coming into force in December 2000 of the EU Water Framework Directive which set a target of achieving 'good water status' throughout the EU by 2015. Related to this are (a) the soon-to-be-revised EC Bathing Water Directive covering nearly 400 coastal and nine inland bathing waters in the UK; (b) the European Urban Waste Water Treatment Directive that relates to coastal discharges and with standards reinforced by the UK Government; and (c) the Operation of the Environment Agency, the Scottish Environment Protection Agency, and the Environment and Heritage Service for Northern Ireland, in which river-quality objectives, abstraction licences, and discharge controls are set and monitored. Water on and from agricultural lands are regarded as public goods.

Protected Areas and Species In last year's *Director's Report*, I gave a brief overview on the National Parks, Areas of Outstanding Natural Beauty (AONB), National Scenic Areas (NSAs), the National Forest, Sites of Special Scientific Interest (SSSIs), the National, Local, Forest, and Marine Nature Resources. Some of these relate to the Convention Concerning the Protection for the World Cultural and Natural Heritage, as adopted by UNESCO in 1972, ratified by the UK in 1984, and by mid-2002 ratified by 172 nations. Other relevant international conventions include (a) the 1971 Ramsar Convention on Wetlands of International Importance especially as Wildfowl Habitat; which came into force in the UK in May 1976, covering 169 designated sites covering 854,389 hectares, and overseen by the UK Ramsar Committee. (b) The 1992 Convention on Biological Diversity ratified by the UK in June 1994, and with the prime objectives of the conservation of biological diversity, the sustainable use of biological diversity, and the equitable sharing of benefits derived from the use of genetic resources. Out of this Convention arose the 1994 UK Biodiversity Action Plan, the 1995 Report of the UK Biodiversity Steering Group, and the subsequent *Sustaining the Variety of Life: 5 years of the UK Biodiversity Action Plan* published in March 2001. By 2002, there were over 160 local biodiversity action plans being developed throughout the UK. (c) The 1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which came into force in the UK in July 1975. The 158 signatory countries ban trade in around 30,000 endangered and likely-to-be endangered species. (d) The 1979 Convention on Conservation of Migratory Species of Wild Animals – the Bonn Convention – that came into force in the UK in October 1979, and has the objectives of protecting listed endangered migratory species such as bats, birds, cetaceans, seals, and marine turtles. (e) The 1979 Bern Convention on the Conservation of European Wildlife and Natural Habitats came into force in the UK in June 1982, with the objectives of conserving wild flora and fauna in their natural habitats, most notably when setting planning and development policies. (f) The Council (EC) Regulation on the Protection of Species of Wild Fauna and Flora by Regulating Trade Therein, which came into force in the UK in June 1997, standardising wildlife trade regulations across the EU, and protecting around 30,000 plant and animal species, many of which are relevant to agricultural habitats. (g) Finally, within the UK, the Wildlife and Countryside Act 1981 gives legal protection to specified wild plants and animals, lays down a close season for wild birds, and details penalties for persons found guilty of an offence under the Act.

UK Agriculture

Overview The publication *Agriculture in the United Kingdom 2002* is the fifteenth in a much-consulted, highly regarded, and authoritative series which succeeded the *Annual Review of Agriculture*. Produced by the Department for Environment, Food and Rural Affairs (Defra), the Scottish Executive Environment and Rural Affairs Department, the Department of Agriculture and Rural Development (Northern Ireland), and the National Assembly for Wales Agriculture and Rural Affairs Department, it relates to a massive compendium of data on the Defra website, particularly at 'Economics/Statistics' under 'Publications' (www.defra.gov.uk/esg/m_publications.htm). Related websites are listed on p128 of *Agriculture in the United Kingdom 2002*.

FMD No new cases of Foot-and-Mouth Disease (FMD) were recorded in 2002, following the most severe outbreak of the disease since 1967-1968, an event that drastically affected the rural economy of the UK during 2001. For the purposes of international trade in animals and animal products, the UK regained its status as an FMD-free country in January 2002, but the reputation of the UK in this regard had been severely blighted, not least as the FMD outbreak came soon after the prolonged and damaging occurrence of bovine spongiform encephalopathy (BSE). As debate continued as to the handling, cost and legality of the official pre-emptive slaughter policy, three inquiries were launched during this disease outbreak; from these inquiries came three important reports. The first was *Farming and Food: A Sustainable Future* produced by the Policy Commission on the Future of Farming and Food in January 2002, which led to three papers produced by government in December 2002: *The Strategy for Sustainable Farming and Food – Facing the Future*; *Response to the Report of the Policy Commission on the Future of Farming and Food by HM Government;* and *Farming and Food's Contribution to Sustainable Development – Economic and Statistical Analysis*. The other two reports were a scientific report by the Royal Society on the transmission, prevention, and control of epidemic outbreaks of infectious diseases in livestock, and *Foot and Mouth Disease: Lessons to be Learned Inquiry Report*. In November 2002, the Government responded with its *Response to the Reports of the Foot and Mouth Disease Inquiries*. A consequence of livestock disease outbreaks was the bureaucratic effort put into the identification tagging, registration and recording of movements of livestock.

Economic Contribution Provisional data in the calendar year 2002 edition indicated that the contribution of agriculture to the total UK economy gross value added (GVA) as a percentage of total GVA at current prices was similar to that of 2001 (revised) at 0.8%, contrasting with an average of 1.5% during 1991-1993, or 1.0% in 1998. At current prices, the GVA in 2002 equated to £7.117 billion compared with an upwardly revised figure of £6.850 billion for 2001, but caution is needed because GVA measurements are prone to rapid changes with sharp movements in commodity prices. It is to be stressed that many of the figures given for previous years have been revised in the light of changes in the scope and nature of the data and improvements in statistical methods. Agriculture is said to be about one tenth the size of tourism, but tourism is in part dependent on agriculture. Using the revised basis for calculating the workforce in agriculture that includes sponsors of farmers, partners and directors, as well as those on work-related government training schemes, about 1.9% of the total workforce was employed in agriculture (550,000), compared with 2.4% (637,000) during 1991-1993. About 50% of the workforce was part-time. As before, the data do not take into account the large portion of the UK workforce that is involved with upstream and downstream activities directly dependent on agriculture, ranging from parts of the public sector (staff in government departments and their agencies and institutes, Research Councils and their institutes, higher-education and further-education bodies, various EU-related groups) to several parts of commerce and the private sector (food processing, storage, distribution, and retail; the industrial feedstock industry; restaurants, hotels, and the tourist trade). For comparison, the EU Farm Structure Survey carried out in 1999/2000 and reported in 2003, showed that around 75% of the 13.5 million people employed in European agriculture work part-time. About 90% of farm workers in Greece and Italy were part-timers, but less than 60% worked part-time in Belgium, France, The Republic of Ireland, and The Netherlands. Analysis of the family labour force revealed that over 40% of family workers were over 55 years and work part-time.

An analysis of the UK food chain using data from recent years attempts to place into context the positioning of farmers and primary producers addressing 59 million consumers and food exports of £8.7 billion, of which £0.7 billion were unprocessed, £3 billion lightly processed, and £5 billion highly processed products. The farmers and primary processors feed into food and drink manufacturing, which includes primary processing through milling, malting, slaughtering, washing and packaging, through several other stages to the production of complex, multiproduct foodstuffs; the GVA of food manufacturing is around £19.8 billion, involving 454,000 jobs in 7,700 enterprises, far fewer than the 233,000 enterprises of farmers and primary producers. The distribution component involved in all parts of the food chain was not quantified. Wholesalers represent a significant part of the chain, with the GVA of agricultural wholesaling amounting to £667 million, 23,000 jobs, and 3,200 enterprises. The food and drink wholesalers, however, have a considerably larger GVA of £6.9 billion, employing 191,000 in 14,500 enterprises. Interaction with the 59 million UK consumers who have total expenditure on food, drink, and catering of £133 billion is through household expenditure on food and drink of £71 billion spent with retailers and £62 billion on non-residential catering services. In 2003, *The Times* was able to publish an article under the headline '*Can't cook. Won't cook. Don't care. Going out. Higher incomes, falling prices and TV chefs drive Britain from the kitchen into the restaurant'.* The retailers have a GVA of £17.6 billion, employ 1,147,000, and comprise 68,300 enterprises but are dominated by a few major multisite retailers. Non-residential caterers have a slightly smaller GVA of £16.5 billion but comprise 104,300 enterprises with 1,404,000 jobs. Thus, the total employment in the UK food chain, as measured in June 2002, amounted to nearly 3.8 million people, only around half a million of which were in production agriculture. As has been pointed out before, there is little publicly funded research and development support for the food chain beyond the primary producer, and even that has been increasingly directed towards 'policy-related' research under the guise of market failure, rather than R&D that is aimed at wealth creation and enterprise. This is evident in the relatively poor level of royalty- and licence-yielding income relative to research spend in the UK; SCRI, however, has been especially successful in generating marketable outcomes to its R&D effort through Mylnefield Research Services Ltd.

Gross fixed capital formation (GFCF) in agriculture at current prices in 2002 was provisionally estimated at £2.318 billion, some 1.6% of national GFCF. Imports of food, feed and drink were estimated to be £18.905 billion, some 8.4% of total UK imports, of which £12.012 billion came from the EU, and £10.321 billion was for food, feed, and non-alcoholic drinks. Exports of food, feed, and drink was estimated to amount to £8.950 billion, £5.537 billion of which went to the EU, of which £4.229 billion was for food, feed, and non-alcoholic drinks, and £1.307 billion for alcoholic drinks. UK self-sufficiency in food in 2002 was 62% in all food, and 74.9% for indigenous-type food, indicating a declining trend in self-sufficiency since 1988 when the current series of reports began.

Household final consumption expenditure (formerly 'consumer's expenditure' until the European System of Accounts was adopted in 1998) for food and alcoholic drinks at current prices provisionally amounted to £140.978 billion, compared with £133.669 billion in 2001. This was 21.2% of total household final consumption expenditure, of which 9.5% was spent on household food, 5.8% on food eaten outwith the home, and 5.9% on alcoholic drinks. The remarkable efficiency of agriculture is illustrated by the data on retail price indices, where 1995 is equivalent to 100 : food was 108.9, alcoholic drinks 118.8, and all items 118.2.

The component countries of the UK varied in the relative importance of agriculture to their economies. On a UK level, the gross output of agriculture was £15.508 billion, and a total income from farming of £2.356 billion, and 0.8% share of total GVA at basic prices and a 1.9% share of total regional employment. Gross output for England was £11.493 billion, Scotland £1.861 billion, Northern Ireland £1.142 billion, and Wales £1.012 billion. Total income from farming (TIFF) was £1.845 billion for England, £0.268 billion for Scotland, £0.127 billion for Northern Ireland, and £0.116 billion for Wales. The Office of National Statistics was unable to provide data for the share of total regional GVA, but the shares of total regional employment were 1.5% for England, 2.7% for Scotland, 7.2% for Northern Ireland, and 4.5% for Wales. This regional pattern of employment was similar to that of the previous year, other than slight declines in the share of employment in Scotland, Northern Ireland, and Wales. As an aside, organic farming was reported by the Scottish Agricultural College to be worth just £148 million a year to farmers in the UK, but around £1 billion retail. Politically, it seemed from media reports that the greatest attention in rural matters was paid to curtailing hunting with dogs to the exclusion of the critical issues facing agriculture, food, tourism, international competitive position, enterprise, and rural deprivation.

Land Areas Agriculture dominates the UK landscape and land management. In June 2002, the total area of UK agricultural land, plus common grazing, was estimated at 18,388,000 hectares, some 77% of the total land area of the UK; 4,573,000 hectares were down to crops, and 33,000 hectares were bare fallow. These figures compare with an average of 18,864,000 hectares devoted to agriculture, and 4,819,000 hectares down to crops in the period 1991-1993. With regard to crop areas, the area devoted to cereals rose by 7.7% from the 2001 figure of 3,014,000 hectares to 3,245,000 hectares, reflecting the 22% rise in the wheat area from 1,635,000 hectares to 1,996,000 hectares. There was a slight rise in the area down to rye and mixed corn to 9,000 hectares, and a rise in the oats area to 126,000 hectares, and triticale remained at 14,000 hectares, but barley growing declined by 12% from 1,245,000 hectares to 1,101,000 hectares. For other arable crops, the potato area declined from 165,000 hectares to 158,000 hectares, contrasting with the 176,000 hectares grown on average in the period 1991-1993. There was also a decline in the area down to other arable crops not including potatoes, from 1,103,000 hectares in 2001 to 993,000 hectares in 2002. This was accounted for by the drop in areas down to oilseed rape (404,000 hectares to 357,000 hectares), peas for harvesting dry and field beans (276,000 hectares to 249,000 hectares), sugar beet not for stockfeeding (177,000 hectares to 169,000 hectares), linseed (31,000 hectares to 12,000 hectares), and other crops (214,000 hectares to 204,000 hectares). The hop area remained at 2,000 hectares. A small increase was noted in the area devoted to horticulture, from 173,000 hectares in 2001, to 176,000 hectares in 2002, a figure that should be compared with the average of 203,000 hectares cultivated in the period 1990-1992, or even an average of 196,000 hectares in the period 1991-1993. Vegetables grown in the open accounted for 124,000 hectares; orchard fruit including non-commercial orchards for 26,000 hectares; ornamentals including hardy nursery stock, bulbs, and flowers for 15,000 hectares; soft fruit including wine grapes for 9,000 hectares, and finally glasshouse crops for 2,000 hectares.

An interesting facet of analysing UK agriculture is applying the concept of European Size Units (ESU), defined as a measurement of the financial potential of the holding in terms of the grossed margins that might be expected from the crops and stock, with a threshold of 8 ESU judged to be the minimum for full-time holdings. By 2000, 68.1% of UK holdings were 8 ESU and over. Specialised commercial holdings are generally thought to exceed 16 ESUs.

The Crown Estate is one of the UK's largest and oldest unitary estates comprising (a) a Rural Estate of 109,133 hectares of agricultural land, forests, residential and commercial property in England, Scotland, and Wales, in addition to 22 mineral leases; (b) the Windsor Estate of 6,300 hectares that includes the Windsor Great Park and Ascot Racecourse; (c) the Urban Estate of over 600 commercial properties; and (d) the Marine Estate of over 55% of the foreshore, beds of tidal rivers and estuaries, and almost all of the seabed out to the 12 nautical-mile territorial limit around the UK; it also includes the rights to explore and exploit the natural resource of the UK Continental Shelf. Since 1760, the annual surplus of the Estate has been surrendered by the Sovereign to Parliament through the Exchequer to help meet the costs of civil government, and the Sovereign in return receives the Civil List and the Government is able to provide additional expenditure in support of the Sovereign. Neither the private estate of the Sovereign, nor the property of the Government, the Crown Estate is classified as part of the hereditary possessions of the Sovereign 'in right of the Crown'.

In January 2003, the Scottish Parliament passed a package of laws under the land reform bill that gave legal right to as-yet-unspecified responsible public access to the Scottish countryside, including private estates. Small and self-defining rural groupings will have first rights to buy land, using public funds. Highland crofting communities would be able compulsorily to acquire land and attendant fishing and mineral rights from land owners. The quasi-nationalisation legislation was opposed by landowners, and likened unto the land grabs in Zimbabwe and Soviet-style economies. Supporters, however, thought it redressed the iniquity of the 19^{th} century Highland clearances and the unequal concentration of land ownership into the hands of a few.

Production Cereal production as harvested rose from 18,991,000 tonnes in 2001 to a provisional level of 23,114,000 tonnes in 2002 having a value of £2.192 billion – the value figure includes arable area payments, but excludes set-aside payments and farm-saved seed, and taxes, where applicable are deducted. Cereal imports from the EU amounted to 2,124,000 tonnes, and 788,000 tonnes from the rest of the world. Exports, however, to the EU were 2,428,000 tonnes, and 357,000 tonnes to the rest of the world. Total domestic use was 20,884,000 tonnes. The major cereals were wheat and barley. Wheat production in 2002 was 16,053,000 tonnes, at a yield of 8 tonnes *per* hectare, and a value of production of £1.490 billion, a figure including £453,000 of subsidies. The average value of production during 1991-1993 was £1.718 billion. Milling wheat averaged £71 *per* tonne and feed wheat £63 *per* tonne. Exports to the EU were 1,462,000 tonnes and 270,000 tonnes to the rest of the world. Imports from the EU were 745,000 tonnes and 495,000 tonnes from the rest of the world. Of the 12,967,000 tonnes of wheat used domestically, 5,627,000 tonnes were used on flour milling; 6,234,000 tonnes in animal feed; 300,000 tonnes for seed; and 806,000 tonnes for other uses and waste. Barley, one of SCRI's mandate crops, recorded a decrease in production from 6,704,000 tonnes in 2001 to just 6,192,000 tonnes in 2002, contrasting sharply with an average of 7,010,000 tonnes in the period 1991-1993. There was a yield increase to 5.62 tonnes *per* hectare. The value of production, excluding farm-saved seed, was £623 million, down on £725 million in 2001, an average of £805 million during 1991-1993. Malting barley achieved an average of £73 *per* tonne, and feed barley just £58 *per* tonne, comparing adversely with £124 and £112 *per* tonne respectively during 1991-1993. Imports of barley from the EU were 51,000 tonnes and 34,000 tonnes from the rest of the world, whereas exports to the EU were 811,000 tonnes, and 86,000 tonnes to the rest of the world. Domestic consumption was 5,663,000 tonnes, or 115% of total raw supply for use in the UK. Brewing and distilling accounted for 1,953,000 tonnes, animal feed 3,508,000 tonnes, seed 160,000 tonnes, and other uses and waste 43,000 tonnes. As before, the main beneficiary from UK malting barley was the UK Treasury. Oat production rose in 2002, to 758,000 tonnes with a value of £71 million; the average figures in 1991-1993 were 501,000 tonnes with a value of £61 million. Milling and feed oats averaged £58 *per* tonne. With imports of 15,000 tonnes from the EU, and exports of 145,000 tonnes, and domestic use of 582,000 tonnes (mainly for milling and animal feed), production was 121% of total new supply for use in the UK. Concern was beginning to be voiced about the impacts of the Atkins Diet on potato and cereal products.

The production of potatoes, another of SCRI's mandate crops, was 6,375,000 tonnes in 2002, down from 6,498,000 tonnes in the previous year, and an average of 7,085,000 tonnes during 1991-1993. Early production was 219,000 tonnes and maincrop 6,156,000 tonnes. The value of production was £463 million, sharply down from £637 million in 2001 and £750 million in 1999. Average prices paid to registered producers averaged £110 *per* tonne for earlies and £81 *per* tonne for maincrop. Supplies from the Channel Islands were 46,000 tonnes and imports were 1,284,500 tonnes. Imports comprised earlies (165,000), maincrop potatoes (204,000 tonnes), seed (38,000 tonnes), and processed (raw equivalent) of 878,000 tonnes, all of which derived mainly from the EU. Exports were just 363,000 tonnes, consisting of 136,000 tonnes raw, 140,000 tonnes processed (raw equivalent), and 87,000 tonnes of seed. Domestically, 7,309,000 tonnes of potatoes were used, 5,987,000 tonnes for human consumption; 399,000 tonnes for seed for home crops, including imported seed; and 923,000 tonnes as chats, waste, and retained stockfeed. Production was 87% of total new supply for use in the UK.

Of the other arable crops, oilseed rape production rose to 1,437,000 tonnes in 2002 from 1,157,000 tonnes in 2001, despite the area planted reducing to 432,000 hectares as yield increased to 3.33 tonnes *per* hectare compared with 2.56 tonnes *per* hectare in 2001. The value of production was £294 million, £81 million of which came from subsidies. Overall subsidy payments fell by 22% reflecting both the reduced planting area and a reduction in the subsidy rate. Linseed production showed a sharp contraction: planting area was only 13,000 hectares contrasting with 213,000 hectares in 1999, and with a yield of 1.43 tonnes *per* hectare, production was just 18,000 tonnes, its lowest level since 1987, and to be compared with 302,000 tonnes in 1999. The value of production was £6 million, £3 million of which arose from subsidies but still a 73% decline in subsidy payments. Sugar beet production based on 'adjusted tonnes' at standard 16% sugar content rose to 9,435,000 tonnes in 2002, from 8,335,000 tonnes in 2001, and had a value of £272 million. Sugar content averaged 17.7%. The average market price for all sugar beet, including transport allowance and bonuses, was £29 *per* adjusted tonne. UK sugar production from sugar beet was 1,390,000 tonnes on a refined basis; imports amounted to 1,309,000 tonnes, and exports were 487,000 tonnes.

The combined value of peas for harvesting dry and assumed to be used for stockfeed (80% of pea production) and field beans used mainly for stockfeed fell by 12% to £125 million in 2002, compared with £142 million in 2001. Subsidies amounted to £61 million. With a yield of 3.43 tonnes *per* hectare, stockfeed pea production was 233,000 tonnes compared with 3.54 tonnes *per* hectare and 295,000 tonnes the year before. Field bean yield was 3.85 tonnes *per* hectare on164,000 hectares giving a production of 632,000 tonnes. UK production and the associated public-sector R&D do not adequately address the challenge of substituting for imports amounting to 70% of vegetable protein used in the EU.

Horticulture Horticulture demands special mention. It continued to be an industry generally perceived to be of great social and economic benefit to the UK, but structurally dominated by small-scale producers lacking both capital and influence in a market dominated aggressively by a few supermarkets readily able to tap into highly competitive global markets. The relatively small public-sector R&D effort was dispersed across a phenomenally wide range of species, pests and diseases, growing systems, and types of science. Vegetables were cultivated on 143,000 hectares, only 1,000 hectares of which were protected. In value terms, however, vegetable production was £647 million grown in the open, a decrease of 11% from the previous year, and £301 million under protection. A small subsidy payment of £4 million arose from arable area payments for peas harvested dry. The main vegetable crops were cabbages, carrots, cauliflowers, lettuces, mushrooms, peas, and tomatoes. Fruit production in the form of commercial orchards only, and soft fruit excluding wine grapes, took place on 33,000 hectares and having a total value of production of £257 million. Orchard fruit was valued at £79 million (mainly desert apples, culinary apples, and pears) and soft fruit £162 million (mainly strawberries and raspberries). Ornamentals were produced on just 20,000 hectares but had an estimated value of £726 million in 2002, comprising flowers and bulbs in the open and forced flower bulbs (£31 million), protected crops (£267 million), and hardy ornamental nursery stock (£428 million). A Government target, unique in EU countries, to reduce the use of peat in growing media by 90% by 2010 was regarded as unrealistic by many growers. Peat replacement by green wastes will require R&D on the effects of sterilisation, supplementation, storage, and packaging, and agreed standards will need to be formulated. Alternatives to green waste include coir, grain husks, forestry wastes and residues, and inorganic materials. Around £1.3 billion was spent on 377 million flowers and £200 million on 50.8 million indoor plants in 2002, with an average annual expenditure *per* person on flowers or ornamentals of £26. Some 80% of flowers sold in the UK were imported, with a large proportion sourced *via* The Netherlands. There were about 6,700 florists and 450 British professional flower growers; nearly 50,000 jobs were attributable to horticulture, including pickers and packers.

Livestock Feed Purchased livestock feeding stuffs, taking into account imports and deducting exports, for cattle, calves, pigs, poultry (including feed produced by retail compounders but not from integrated poultry units) and other livestock amounted to 9,959,000 tonnes in 2002, valued at £2.175 billion. The figures were adversely affected by the aftermath of FMD. A 6% increase was recorded in the volume of compound feed for the poultry sector.

Seeds Total purchased seeds in the UK totalling 1,027,000 tonnes and valued at £295 million were closely similar to the levels recorded in 2001. There were small declines in the volumes of certified cereal grain and root and fodder crops, but an increase in seed potatoes (including farm-saved seed). In recent years, it has been necessary in the UK to stress to policy makers the pivotal rôle of plant breeding in generating improved cultivars/types for agriculture, horticulture, and forestry. In concert with advances in automation and agrochemicals, the products of plant breeding are responsible for the continuing efficiency of production. Unfortunately, the European plant breeding industry continued to be disadvantaged in international markets principally by regulatory conditions and retailer resistance to the products of genetically modified cultivars. Fortunately, however, for LDCs and populous countries, the CGIAR system fully recognises and appreciates the fundamental economic and social rôle of plant breeding. Further contractions took place in the UK plant-breeding and agrochemical industries.

TIFF Much cited but often the cause of confusion over the performance of agriculture, the Total Income From Farming (TIFF) figure refers to business profits and income generated by production with the agricultural industry, including subsidies, to those with an entrepreneurial interest in the agricultural industry (*e.g.* farmers, growers, partners, directors, spouses, and most other workers). Always stressed is the fact that TIFF is remarkably sensitive to small changes in the values of outputs and inputs, compounded by the provisional nature of data for 2002. Moreover, payments for livestock destroyed for FMD and associated welfare purposes were excluded from TIFF on the grounds of being exceptional losses as defined in the European System of Accounts 1995. TIFF is derived by deducting interest, rent, and paid labour costs from Net Value Added (NVA) at factor cost (*i.e.* at basic prices plus other subsidies (less taxes on production *e.g.* agri-environment payments, set-aside)). NVA at factor cost is regarded as a reliable measure of value added by the industry because it includes all subsidies but it makes no allowance for interest, rent or labour costs. According to *Agriculture in the United Kingdom 2002*, TIFF was estimated to have risen by 15% (14% in real terms) to £2.356 billion compared with its level in 2001. The TIFF figure for 2002 was estimated to be 56% (62% in real terms) below its peak in 1995, after more than doubling between 1990 and 1995. NVA at factor cost increased over 2001 by 5% to £4.990 billion. Diversification was encouraged as a way to increase rural incomes. According to the aggregate balance sheets in terms of assets and liabilities for UK agriculture, at current prices the net worth in 2002 was, provisionally, £106.968 billion compared with an updated figure of £102.767 billion for 2001. Net worth was reckoned to have reached its highest level in real terms since 1980, as have total assets, and liabilities were at their lowest level since 1980, too.

Productivity Productivity of the UK agricultural industry can be assessed in various ways. It is neither adequate nor reasonable simply to measure the volume of output, labour productivity, profitability in a single financial year, its relation to imports *etc.*; rather it should be a measure of resources utilised to convert inputs into outputs. Typically, productivity measures are based on the ratio of the volume of outputs and the volume of inputs. Productivity is regarded as the key determinant of the economic sustainability of UK agriculture, an underestimated industry that underpins the food chain and related environmental and social benefits. Comparisons at international, national, and regional levels, or from year to year are fraught by complexities arising not only from obtaining reliable data but also by factors regarded as exogenous such as climate, topography, location *etc.* Total factor productivity in terms of the volume of output leaving the industry *per* unit of all inputs, including fixed capital and paid labour (a significant, but difficult to quantify, portion of agricultural labour is unpaid), has increased by 43% since 1973. This growth reflects increases in labour productivity (volume of NVA) *per* unit of paid and entrepreneurial labour) which has more than doubled since 1973. Throughout the 1990s, output remained static but inputs (most especially labour costs) have decreased in line with improved automation and a massive drop in the numbers employed. Using volume indices 1995=100, provisional productivity measurements for 2002 were 96.2 for final output (gross output less transaction) within the agricultural industry; 142.0 for NVA *per* annual work unit of all labour (full-time equivalent); and 111.7 for final output *per* unit of all inputs (including fixed capital and labour). The paid labour costs, which include payments-in-kind, National Insurance contributions, redundancy payments *etc.*, were estimated to be £1.907 billion in 2002, compared with £1.909 billion the year before. Minimum wage legislation does not apply to the self-employed that constitute much of the agricultural and horticultural workforce, were it to do so, then much of UK agriculture would collapse, along with the profitability of enterprises further up the food chain.

Farming Incomes in the EU From 2001 to 2002, there was great variation in the percentage changes in income derived from agricultural activity across member states of the EU. According to the much-troubled Eurostat, see Eurostat-Statistics: *Statistics in focus*, December 2002; Indicator A which is based on NVA at factor cost (deflated by the GDP price index) and measuring agricultural income *per* annual work unit (full-time worker equivalent), there was a decline of 3% overall in the EU, and declines recorded in ten of the fifteen member states. Rises were noted in Finland (7.3%), Greece (5.7%), UK (3.9%), Spain (1.2%), and Luxembourg (1%). Declines were recorded in France (-0.9%), Sweden (-1.5%), Italy (-1.6%), Portugal (-2.2%), Austria (-2.8%), The Netherlands (-7.5%), Belgium (-7.7%), the Republic of Ireland (-11.4%), Germany (-18.0%), and Denmark (-26.3%).

Relative Importance of Agriculture in the EU With data only available for 2000, Eurostat estimated the relative importance of agriculture in the 15 EU member states, measuring the share of agriculture in national Gross Value Added (GVA) at market prices and employment. Overall, agriculture accounts for 1.4% of EU GVA and 4.0% of employment. For the UK, only 0.4% of the national GVA at market prices (*i.e.* it excludes directly paid subsidies) and 1.4% of the workforce are attributable to agriculture. For Sweden, the figures are 0.5% and 2.4%; Finland 0.5% and 5.0%; Luxembourg 0.5% and 2.4%; Germany 0.7% and 2.5%; Austria 1.0% and 5.9%; Belgium 1.0% and 1.9%; Denmark 1.7% and 3.5%; France 1.8% and 3.9%; the Republic of Ireland 1.8% and 7.6%; Portugal 2.0% and 11.9%; The Netherlands 2.1% and 3.2%; Italy 2.2% and 4.8%; Spain 3.2% and 6.2%; and Greece 4.7% and 16.5%. Agriculture has the least importance to the national economy in the UK, but the most in Greece. Eurostat income indicators reveal the declining performance of UK agriculture compared with that of the EU as a whole. In 2001, NVA at factor cost of agriculture *per* total annual work unit *i.e.* income *per* full-time worker equivalent, has increased on average in the 15 member states (EU-15) since 1995 whereas it has declined by 40% in the UK. Thus, on the basis of the average index 1994-1999=100, the UK figure was 60.5 and 112.1 for EU-15. For net entrepreneurial income from agriculture, there were declines in both the EU as a whole and the UK, but the fall in the UK (-67%) was more severe than that of EU-15 (-12%) *i.e.* 33.0 *versus* 88.5.

Subsidies Many have written at length on the origin, rationale, and development of the Common Agricultural Policy (CAP), and its market-distortion effects, complexity of operation, enormous costs, potential for corruption, currency exchange-rate turmoils, political manipulations to favour certain types of agriculture but exclude others, effects on international trade negotiations, and the need to put into context the challenge of having a sustainable rural economy, and protecting production agriculture from income parasitism further up the food chain. CAP-related subsidies supporting UK agriculture are supplemented by other types of support. The majority of subsidies come in the form of direct payments linked to production. There are also market support measures given by intervention purchases and import tariffs, both of which impact on consumer prices. Support is also given increasingly by direct payments linked to rural development. Public expenditure relating to agriculture covers diverse activities including the operation of market regulation, certain areas of animal health and disease control, education, research, advice, food safety and standards, and relevant public-sector staffing and the construction, maintenance and operation of associated facilities; some of these costs, of course, do not directly benefit producers but are designed to benefit consumers and commerce more generally.

Total public expenditure under CAP and on national grants and subsidies was forecast to be £3.1192 billion in the financial year 2002-2003. This comprised (a) total direct product subsidies, including the Arable Area Payments Scheme, livestock subsidies, and agri-monetary compensation, totalling £1.9227 billion; (b) total other subsidies on production, including the agri-environment, conservation, and rural schemes, as well as special area support for less-favoured areas, and animal disease payments, totalling £0.4845 billion; (c) total capital grants, transfers and other payments, including diversification and FMD-related payments, totalling £11.6 million; and (d) total CAP market support, including cereals, sugar, milk products, processed goods, and livestock-related payments, totalling £0.7004 billion. The figures for 2001-2002 were distorted by the impact of the compensation payments and disposal schemes arising from the FMD outbreak, where total public-sector expenditure was £4.6639 billion. In 2002, the agricultural industry received an estimated £2.578 billion in direct subsidies less levies, compared with £2.402 billion in 2001.

Modulation remained a contentious issue. It is a process to recycle or vire a proportion of direct CAP payments under the various commodity regimes, and was introduced in the UK, at a flat rate of 2.5% in the 2001 scheme year. The funding raised was used to help fund the Rural Development Programme (RDP), incorporating Countryside Stewardship, Tir Gôfal, Countryside Premium, Environmentally Sensitive Areas, and certain of the less-favoured-area-schemes. In 2002, modulation was raised to 3% of subsidy payments in order to help fund the RDP, and the rate is expected to rise to 4.5% by 2005. The funding raised by modulation is matched by the UK taxpayer, and the total spent in the RDP to support the rural economy. On an accruals basis, modulation was estimated to have reduced arable and livestock subsidies by *circa* £60 million in 2002. Changes to the subsidiary regime in 2005 raised questions about the willingness of taxpayers to pay for 'public goods'.

Environmental scheme payments in 2002 were estimated to amount to £245.7 million. Organic conversion payments were £41.7 million in England, £2.8 million in Wales, £7.1 million in Scotland, and £1.6 million in Northern Ireland. Payments relating to Environmentally Sensitive Areas amounted to £48.2 million in England, £7.5 million in Wales, £10.2 million in Scotland, and £4.7 million in Northern Ireland.

Still to be resolved is the future basis of allocating subsidies under a modified CAP regime. Confusion exists as to whether subsidies will be given to existing subsidy-receivers, or will be spread out to those agricultural and horticultural enterprises currently unsupported, such as fruit, pig, and poultry producers. The proposed decoupling of subsidies from production quotas is meant to make farmers more market-oriented, but could maintain unfairness, not least in respect of entirely different approaches by other member states of the EU, and political whims. In summary, the Mid-Term Review package proposed for the CAP has the potential to reshape EU agriculture without lessening the degree of bureaucracy. It comprises a complex of direct single-farm payments decoupled from production (but with an option to retain some coupled payments); cross-compliance to environmental, food safety, animal health and welfare, and phytosanitary standards; widened rural development policy options; reductions in direct payments (modulation) for farms receiving in excess of €5,000; national envelopes to redirect support payments; CAP financial discipline to prevent spending overshoots; a complex dairy reform package; reductions in cereals support, coupled aids, notably crop-specific aids for protein and energy crops; and the potential for more reforms to other sectors. Payment dates will be delayed compared with most of the current schemes. One of the most important aspects is that of statutory management requirements relating to numerous Directives and regulations, increasing further the vulnerability of agriculture to litigation.

Environmental Impacts of UK Agriculture
Governments worldwide are attempting to assess more accurately the environmental impacts of the various components of the rural economy, and in turn are reviewing the sustainability of various types of agriculture. Various sustainability indicators, as well as socially desirable and politically desirable indicators of the manifold impacts of agriculture on the environment, have been described, and research conducted to quantify those impacts. Economic valuations are particularly fraught in trying to guage environmental public goods, especially visual amenity (for agriculture shapes the landscape), air and water quality, biodiversity, recreational access *etc.* (see *Farming and Food's Contribution to Sustainable Development : Economic and Statistical Analysis.* December 2002. www.defra.gov.uk/farm/sustain/newstrategy/index.htm for information on the positive and negative impacts of agriculture on the environment). The Office for National Statistics compiles and is in the process of refining environmental accounts for the UK, as satellite accounts to the National Accounts. Both the EU and the UN recommend frameworks for developing environmental accounts, making cross-country comparisons more straightforward.

The environmental impacts of UK agriculture are massive: (a) around 75% of land cover is agricultural, providing the rural landscape (visual amenity) which for the most part is attractive and generates tourism and permits various recreational activities; (b) agriculture sustains diverse habitats, landscapes, historical sites, and wildlife habitats; (c) as an economic activity, agriculture sustains a rural and associated social infrastructure, justifying industries upstream and downstream of agriculture; (d) management of the soil resources is a major consideration, maintaining soil structure, preventing erosion, retarding pollution, and facilitating water management and flood control; (e) poor farming practices can damage public goods (*e.g.* polluting ground waters, rivers, soils, and the atmosphere; lowering biodiversity) by eliminating ecological refugia and dispersal corridors such as hedgerows and field margins; destroying habitats and reducing characteristic farmland-related flora and fauna, and adversely affecting historic sites and pre-Roman field patterns; increasing the prevalence of flooding, *etc*; (f) unfettered and irresponsible use of public rights-of-way, open-access land, and wayleaves for utilities can have deleterious effects both on agriculture as an economic activity, on erosion, pollution, and visual amenity, even though free access provides benefit to tourists and urban and suburban populations; (g) the economic health of agriculture affects the rural environment directly and indirectly: in an economic downturn, the maintenance of hedgerows and walls, woodlands, and the general visual appearance can change dramatically, just as subsidy-dependent agriculture can introduce mass-planting of certain crops or high-density livestock grazing unjustified by market needs; (h) simplistic denigration of intensive agriculture ignores the beneficial effects on the provision of cheap food-stuffs and profitability higher up the food chain, as well as protecting more natural habitats from the spread of widespread, lower-efficiency agriculture; (i) agriculture can be the user of finite resources, and the user and creator of energy, the creator and user of greenhouse gases and hazardous chemicals, and be the basis of human well-being as well as act under some circumstances as the source of human health problems; and finally (j) agriculture acts as the lungs, kidneys and guts of urban mankind, and is favoured as a dumping ground for wastes and the treatment of wastes, but Defra estimated that in 2000, agricultural waste accounted for 20% of all UK wastes. Closely tied to environmental impacts is the issue of public perception, and 'concern', however expressed or aggravated. Perhaps the most crucial environmental issue of immediacy is both large-scale and incessant developer-led building on greenfield sites, although GM crops, intensive livestock rearing, the felling of trees and hedgerows, and the use of agricultural chemicals in farming figured most prominently in the Defra analysis of concerns about environmental issues in 2001.

Various UN bodies, the OECD, UN and many governments in both MDCs and LDCs are attempting to create widely accepted sustainability and environmental indicators and targets, as an adjunct to measure and where necessary lessen environmental impacts of agriculture. Bird populations are of special interest in the UK, with the Royal Society for the Protection of Birds and the British Trust for Ornithology being particularly politically influential. On the basis of their distribution throughout rural and semi-rural as well as urban habitats, and the fact that birds have a close proximity to the top of the non-human food chain, wild-bird populations are given a noteworthy degree of prominence in the UK Biodiversity Action Plan, with targets to reverse the decline in populations and to increase range and habitats, all easier said than done given the complex nature of population changes, food availability interactions with the environment, and predator-prey-parasite-disease relations. My preference would be to assess non-sustainability factors and indicators in agriculture, with due allowance for regional habitat variations.

Quantification of the environmental impacts of agriculture is bedevilled by subjective economic valuations and incomplete data sets. According to the Environment Agency (*Agriculture and Natural Resources: Benefits, Costs and Potential Solutions*. May 2002), agriculture contributes 95% to soil erosion overall. Changes in agricultural land use with associated cultivation practices are blamed for increased rainwater run-off which contributes to flooding – usually of houses built on flood plains as a result of wholly inadequate regional drainage and domestic-housing policies.

Direct and indirect energy consumption in agriculture for 2001, but not including the manufacture and distribution of food, was reckoned on 'as supplied to agriculture' basis to be 183.1 PetaJoules (PJ) compared with 240.3 PJ in 1985. The 2001 figure represented only 0.3% of overall UK energy consumption. Energy was used directly for heating and motive power, and this amounted to 48.9 PetaJoules, with the bulk accounted for by petroleum and electricity (24.4PJ and 16.5PJ, respectively). Indirect energy inputs were estimated at 134.2 PJ in 2001, representing fertiliser manufacture (94.6 PJ), animal feeds (20.7 PJ), tractor purchases (10.3 PJ), and pesticide manufacture (8.6 PJ). The long-term trend of indirect energy usage since 1985 has been one of decline, with a questionable presumption by Government that adoption of organic production methods will further depress energy consumption.

Renewables In contrast to consuming energy, agriculture can contribute substantially to the generation of renewable energy. Renewable energy sources in the UK, comprising biofuels, hydro, solar, and wind, accounted for 3.1 million tonnes of oil equivalent in 2001, according to the DTI. Of this, about 2.4 million tonnes was used to generate electricity, and the remainder to generate heat for other purposes. In order to stimulate the development of renewable energy sources, the Non-Fossil Fuel Obligation Renewable Orders were introduced, requiring the regional electricity companies to buy specified amounts of electricity from specified non-fossil-fuel sources, to reach 10% of UK electricity generation by 2010. Such sources are exempt from the Climate Change Levy, and are also promoted by capital grants, R&D programmes, regional planning, and a range of targets. In 2001, 85.6% of renewable energy sources were biofuels and wastes (landfill gas 27%), waste combustion 21.5%, wood combustion 15.1%, other biofuels 11.8%, sewage gas 5.4%, straw combustion (4.8%), hydro was 11.3%, wind and wave 2.7% and geothermal and active solar heating 0.4%. Security of supply in an era of massive energy importation and the winding down of the nuclear industry, leading potentially to social and economic instability (rather akin to, but less drastic than unstable food supplies), began to concern observers of the energy industry.

Agricultural biomass and farm wastes were thought to account for 15% of the inputs for the generation of renewable energy in the UK in 2002, such that 20 PJ – 478,000 tonnes of oil equivalent – came from agricultural sources. Wood fuel from rapidly growing species such as willow and poplar, straw, livestock and food-processing wastes, as well as wind-farms, are becoming recognised as environmentally acceptable and possibly economically viable energy sources. Transport biofuels, biodiesel and bioethanol, can be produced from plants and recycled components in the food chain. Normal farm crops such as cereals, oilseeds, sugar and fodder beet, and potatoes, can act as the source of biofuels, as well as recycled vegetables oils and fats, wood, straw, and household wastes. The EU Biofuels Directive 2003/30/EC, May 2003, requires that the member states submit by July 2004 their national targets for biofuel utilisation by December 2005. The EU guideline is 2% by December 2005, and 5.75% by December 2010. Energy and industrial crops would appear to be a relevant route for meeting Kyoto targets as well as lessening dependence on the importation of fossil fuels. According to *The Facts on Biodiesel and Bioethanol* (2003), produced by the British Association for Biofuels and Oils and Defra, biodiesel can be used either as a blend with mineral oil or neat; ethanol can be used as a blend with petrol or converted to etherised bioethanol and used as a petrol extender. Uptake of the biofuels will only be possible if production costs are lowered and/or there is a reduction in fuel excise duty, and/or fossil fuel prices were to rise. There is no doubt as to the ability of UK agriculture to produce suitable crops for conversion to biofuels if there were sufficient financial incentive; virtually all the current initiatives are economically fragile and small-scale.

Agriculture and Kyoto Targets Undesirable agricultural emissions and pollution have international ramifications in meeting Kyoto targets, affecting the competitiveness of the agricultural industry, affecting the quality of drinking water, suppressing biodiversity on land and in water, and affecting human health. Yet many of the data on the scale of emissions and levels of pollution are not wholly in accord with demonstrable adverse effects. Of the greenhouse gas emissions specified in the Kyoto Protocol, carbon dioxide, methane, and nitrous oxide are thought to be of note in global agriculture. Short-term carbon sinks created directly and indirectly through photosynthesis are more than counterbalanced, so it is thought, by carbon dioxide release from cultivation or tilling of land, draining of peat- and fenlands, and the combustion of fossil fuels in machinery. Unlike methane and nitrous oxide, carbon dioxide emissions are not sourced primarily from agriculture. Methane emissions of about one million tonnes *per annum* are derived from agriculture through the decomposition of animal wastes and gaseous emissions from livestock guts, landfill, coal mines, and other sources. Nitrous oxide is derived from nitrogenous fertilisers and from animal wastes. Other emissions come from uncontrolled and controlled burning of wastes of many types.

Other Agricultural Emissions Emissions also include leached fertilisers and pesticides, which vary in their degradation or immobilisation in the environment, but as agriculture is the largest user of pesticides and veterinary medicines (*e.g.* sheep dip, antibiotics, hormone and growth regulators, disinfectants), then agricultural run-offs and residues are being monitored to unprecedented levels. Livestock farming was claimed to be responsible for 85% of the UK's ammonia emissions to the atmosphere in 1999. According to the Environment Agency, UK agriculture was responsible for 43% of phosphate in surface waters, 29% derived from livestock and 14% from crop fertilisers. Intensive livestock production has led to as-yet-unquantified increases in manure and slurry, bringing with them pathogenic organisms, heavy metals, pharmaceuticals, and eutrophication-inducing ammonia-producing compounds. Farm-yard washings and breaching of slurry tanks were reported to account for more than half of the 2,063 substantiated water pollution incidents involving organic materials in 2000. This did not include the vast production and partial treatment of urban-derived sewage pumped into and polluting the seas surrounding the UK. Other emissions from agriculture frequently inducing complaints from the non-agricultural population include odours, smoke, dust, and allergenic pollens. Noise can also be an unwanted emission.

Quantitative Assessments of Agriculture's Environmental Impacts in the UK In assessing economic valuations of the impacts on the environment of different types of agriculture, allowances have to be made for (a) large areas of uncertainty in the techniques employed; (b) uncertainty in quantifying real impacts as opposed to assumptions; (c) the significance of impacts that have not been or cannot be assessed; (d) properly judging alternative land uses and economic implications that flow from them, such as the impacts elsewhere of sourcing all foods and agriculturally-related services from outwith the UK; (e) associated implications such as livestock and human welfare, including access to foodstuffs; and (f) the standpoint of the author(s) where science, economics, and social perceptions can have a less-than-objective partnership. In the absence of well-developed markets for most environmental goods, any valuations can only be broad-brush, even where inferences are drawn from surveys of opinions; or from the behaviour of other markets subject to environmental influences and essentially assessing so-called 'welfare impacts'; or judging surrogate measures based on goods that have market values, the usual example being the treatment of waste waters, costs that are driven by legislation. Agriculture's damage to natural goods has been judged to be £1.566 billion in 1996 prices (J. Pretty, C. Brett, D. Gee, R. Hine, C.F. Mason, J.I.L. Morison, H. Raven, M. Rayment, and G. van der Bijl. *An Assessment of the Total External Costs of UK Agriculture*. Agricultural Systems, **65**, 113-136, 2000); £1.072 billion at 1998 prices (O. Hartridge and D. Pearce. *Is UK Agriculture Sustainable? Environmentally Adjusted Economic Accounts for UK Agriculture*. CSERGE – Economics paper. September 2001); and £1.227 billion at 2000 prices with biodiversity, landscape, and human-health damage uncosted (Environment Agency. *Agricultural and Natural Resources: Benefits, Costs and Potential Solutions*. May 2002). The positive environmental impacts of agriculture providing environmental services in the form of agricultural landscape, forest and woodland, environmentally sensitive areas, and Sites of Special Scientific Interest were estimated by Hartridge and Pearce to be £594.9 million *per* year at 1998 prices, and £955.5 million including the benefits of creating photosynthetically driven carbon sinks.

Protected Land Areas Designated sites in the UK afford varying degrees of environmental protection by favouring land management practices that yield conservation, biodiversity and other related benefits (see **Protected Areas and Species** above). Collectively, the National Parks, AONBs and NSAs cover 21% of the UK land area, SSSIs and Areas of Special Scientific Interest (ASSIs) in Northern Ireland; cover 7.7% of the UK land area. Other protected areas include Ramsar (wetlands) sites, World Heritage sites, nature reserves, National Trust and Scottish National Trust lands, Nitrate Vulnerable Zones, and various agri-environment, rural stewardship, and countryside management schemes. With modulation, the protected area is set to increase.

IFM and Organic Agriculture Environmental protection is the focus in the UK of two types of agriculture: Integrated Farm Management (IFM) which is an holistic approach to minimise adverse environmental impacts but maintain efficient and profitable production, a system best exemplified by the Linking Environment and Farming (LEAF) scheme; organic farming, which has a more ideological basis, strictly regulating inputs and technologies, and focusing on soil fertility. Organic farming extended to 699,879 hectares by June 2002 but in value terms represented a small part of UK food production.

AIC Agricultural representation in the UK was changed in 2003 by the formation of the 365-member-company Agricultural Industries Confederation, a body that arose from the amalgamation of (a) the UK Agricultural Supply Trade Association (whose members produce *circa* 90% of the UK's annual feed; account for more than 90% of the grain, oilseed, and pulses traded in the UK; and represent more than 80% of the UK's certified seed trade); (b) the Fertiliser Manufacturers Association (whose members comprise 95% of UK fertiliser producers); and (c) a group of distributors supplying more than 90% of the UK's crop protection products as well as agronomy advice. The combined membership had a turnover of £6.5 billion.

An Overview of Modern Agriculture

The transfer from a nomadic hunter-gather existence to one of systematic and organised food and fibre production in settlements of durable housing, with people in stable social groupings deploying tools, keeping livestock, and cultivating crops, is widely thought to have begun about 9000-7000 BC in the Middle East, although there is evidence of crop cultivation in 9000 BC in northern Thailand, and in 7000 BC in north-east Mexico. In terms of scale of operation, however, it is clear from archaeological evidence that the development of agricultural-dependent villages or settlements was most pronounced in the Middle East, in Iraq in about 6750 BC, in Greece in 6000 BC, and in Crete at around the same date. As the journalist A. Browne wrote in *The Times* in April 2003 during the war with Iraq, civilisation was thought to have started in the fertile plains between and around the Tigris and Euphrates rivers. The Bible is replete with references to early cities and sights that were built as a result of successful agriculture. The plough, the wheel, the chariot, picture-symbol records giving way to cuneiform and then a syllabic alphabet for writing, literature, codes of law, accountancy with double-entry book-keeping, banking, astronomy, calendars, discovery of bronze, and the formation of conscript armies all arose in an area that was once the hub of the largest empire mankind had created. By 3000 BC, agriculture had reached Denmark and the British Isles, with genetic adaptation having taken place in the main sources of the agricultural foodstuffs (cereals, sheep, and goats), and widespread adoption of early agricultural technologies, for it is cereal cultivation, and sheep and goat farming, that facilitated the formation of the so-called effective village stage, with its associated level of social organisation. In some parts of Europe, notably in the Danube River area, a primitive slash-and-burn agriculture based on cereals was practised. Slash-and-burn agriculture is still practised in tropical forests and by dry-rice cultivars in the forested hill country of South-east Asia. Areas of forest are felled, burned to provide ash for fertilisation, and cleared such that only stumps and large trees remain. Cultivation is usually by hoe or digging stick, and crop successions haphazard. Weed numbers remain low initially, but depending on soil type, fertility declines rapidly and weed infestations increase. Yields tend to be very low. The area (primitive field) is left fallow, allowing secondary forest or bush to become established, and cultivation shifts to a new area. After a decade or so, the old site may be re-used. This type of agriculture is classed as a form of shifting agriculture with field, as opposed to crop, rotation, and is responsible for degrading the fertility and stability of fragile forest-land soils. Settled communities are not favoured by slash-and-burn agriculture. As the various early civilisations outwith Europe developed in what are now China, Egypt, India, Indonesia, Iran, Iraq, Japan, Mexico, Pakistan, Peru, Thailand, and Vietnam, agriculture took on technologies easily recognisable today – ploughing, drill sowing and dibbling, reaping, threshing, winnowing, irrigation, double (even triple) cropping, crop and livestock selection, food and fibre processing, various types of crop rotation, soil fertilisation, and the creation of transport and trading networks. The plough is the single most important agricultural implement since the dawn of agriculture, used initially to break up compacted soil for planting, and in later versions to control weeds and bury residues. Agricultural output exceeded subsidence-level production, permitting towns and then cities to expand commensurate with being able to feed their expanding populations.

Greek and Roman agriculture was based on crops such as cereals (barley, millet, spelt, wheat), legumes (alfalfa, beans, chick-peas, lupins, peas, vetches), turnips and radishes, olives, and various fruits and nuts. The two-field or crop-and-fallow system was used, wetlands were drained, and various legumes started to be used as green manures. In the two-field system that operated in Europe and the Middle East, arable land was divided into two groups of fields. One group was planted to cereals (barley, rye, or wheat) and the other lay fallow to recover fertility. After cropping, the first group of fields was turned fallow, with livestock turned out to graze on the stubble and fallen grains, enriching the soil with their faeces and urine. By the 8th century, the two-field system started to give way to the three-field system. Native breeds of cattle specific to certain regions were appreciated, and sheep, goats, and pigs were kept in large numbers. Markets, stores, and shipping routes were well established.

In the period 600-1600 AD, the most important technological advances in agriculture were introduced in Europe north of the Alps, perhaps reflecting the fortuitous concurrence of appropriate soil types, equable climates, ready access to water, suitable types of crops and livestock, and societies sufficiently stable to organise land-use-management systems, and construct and utilise tools both to reclaim and exploit fields. In the more advanced areas, horses replaced oxen as a draft animal, aided by the Chinese invention of the padded horse collar that replaced the harness band. In the three-field system, only a third of the land was permitted to lay fallow. In the autumn, one third of the land was planted to barley, rye, or wheat; in the Spring another one third of the land was planted to barley, oats, or legumes (usually beans and/or peas) for harvesting in late summer. The nitrogen-fixation properties of the legumes aided soil fertility and the protein content of their seed was of considerable dietary benefit. Spring planting requires summer rains and so the three-field system was particularly effective in Europe north of the Loire and the Alps. By providing two harvests a year, the risks of crop failure and famine were lessened, the rotation system encouraged more elaborate labour management, and the supply of oats was used as a valuable feed for horses. Land was reclaimed from the sea, marshes, fens, and forests; monastic bodies, monarchs, and their acolytes created large estates; and a formal agricultural literature began to take form, building on the earlier literature and records from Greece, the Roman Empire, the Nile Valley, the Buddhist and Vedic texts, and China. An agricultural recession was visited on large parts of Europe towards the end of the 13th century and much of the 14th century, as wars, human diseases, famine, depopulation, and adverse weather retarded agricultural development. Economic recovery took place during the 15th and 16th centuries, and technological advancements driven by pronounced societal changes became manifest between 1600 to 1800 AD. European agriculture was for two millennia based on the socially restrictive open-field system, best exemplified in the feudal manorial system, in which peasant holdings (strips) were intermixed amongst the different field, usually changing from year to year, spreading the risk of poor harvests. Crop rotation was initially by the two-field system, giving way in later centuries to the more efficient three-field system. An area of land was retained under permanent pasture for common grazing. From the mid-1400s to the mid-1800s, Europe was subject to the Little Ice Age, and was at its coldest during 1645 to 1715 – the Maunder Minimum, named after the astronomer E. W. Maunder (1851-1928). Long winters and cool summers created the conditions for well-documented reports of hunger and famine prompting mass migration, low agricultural yields, and ergotism caused by fungal-infected cereal grains.

At a time when the population in the UK doubled to 10 million during the 18th century, agricultural specialism in most of the arable areas of the countries now constituting the UK was made possible by five developments. Firstly, land enclosures (see the 2001-2002 edition of this *Report*) replaced the old manorial-based co-operative open-field system. Secondly, the Norfolk four-course system was adopted (wheat in the first year, turnips mainly for fodder in the second year, barley undersown with rye grass and clover in the third year, rye grass and clover grazed or cut for fodder in the fourth year – there was no fallow season). Thirdly, improvements were introduced in the nutrition, breeding, and maintenance of livestock, chiefly of cattle, pigs, and sheep. Fourthly, technological advancement took place in the manufacture of ploughs, threshing and fodder-preparation machinery, seed drills, drainage, and irrigation, as well as in crop types, and new types of crop were introduced, especially the potato. Fifthly, there began formal agricultural education and learning through published books and pamphlets, as well as through improvement societies and the active oversight and encouragement of agriculture by Government. As the Industrial Revolution took hold and the rural population transferred out of food production into towns and cities, agricultural production was unable fully to satisfy demand, leading to food imports of commodities normally able to be grown in Great Britain, chiefly of cereals from Poland, Prussia, and Russia. The population began to enjoy agricultural products (fruit, vegetables, spices, nuts, beverages, drugs, dyes, fibres *etc.*) from North America, the Middle East, and Far East, and agriculture became a major activity of the colonies. British farming set the international standards for quality, innovation, efficiency, mechanisation, and specialisation.

Agricultural science and engineering came to the fore during the 19th century, introducing conceptually new designs of ploughs, mole ploughs, cultivators, reapers, threshing machines, steam-powered equipment, cream separators and coolers, and fertilisers, in concert with railroads and steamships for transporting crops and livestock. New supply chains and markets were created as well as specialist labour forces not only to produce but also to process food and industrial materials. At the same time, a number of countries established agricultural research institutes (*e.g.* Rothamsted in England) and colleges (*e.g.* Royal Agricultural College at Cirencester, England).

Modern genetics has its origin in the experimental work of Gregor Mendel (1822-1884), who through experiments on cross-breeding garden peas discovered that the progeny of the parent plants had characteristics such as flower colour and shape of seeds distributed in definite mathematical ratios. He concluded in 1865 that many traits segregated into dominant and recessive alternatives, and that combined traits assorted independently: the particulate native of inheritance was demonstrated. Special mention should be made of Marrhias Jakob Schleiden (1804-1881), botanist and co-founder with Theodor Schwann (1810-1882) of the cell theory, crucial to the development of the life sciences. Schleiden in 1838 stated that the different parts of a plant organism are composed of cells or derivatives of cells. He also recognised the importance of the cell nucleus in living cells, a structure first discovered and named in 1831 by Montrose-born Robert Brown (1773-1858). Schwann propounded the cell theory in animals in 1839, and was also noted for isolating pepsin, discovery of the myelin sheath surrounding peripheral axons, and coining the term metabolism for the chemical changes taking place in living tissues. H. de Vries (1848-1935), C. Correns (1864-1933), and E. Tschermak (1871-1962) independently rediscovered the obscure 1865 work of Mendel, confirming their own work in inheritance.

In 1903, W. S. Sutton (1876-1916) pointed out that the Mendelian ratios could be explained by the cytological behaviour of the chromosomes. In 1911, T. H. Morgan (1866-1945) claimed that certain traits were genetically linked on the chromosome, arranged as genes in a linear file, thereby stimulating the construction of genetic maps. In 1930, R. A. Fisher (1890-1962) in *The Genetical Theory of Natural Selection* established that superior genes have a significant selective advantage, supporting the view that Darwinian evolution was compatible with the science of genetics. Thereafter, the relationships between mutant genes and metabolism described in 1941 by G. W. Beadle (1903-1989) and E. L. Tatum (1909-1975), and the work of O. T. Avery (1877-1955) *et al.* in 1944 on the transfer of DNA molecules in pneumococcus bacteria, were able to provide a background to the groundbreaking model of the structure of DNA by F. H. C. Crick (born 1916) and J. D. Watson (born 1928) in 1953. This model could account for gene replication and the transfer of genetic information. From such work has developed modern molecular genetics.

Plant and animal breeding advances, however, were not reliant on genetical science *per se.* Selection and breeding of crop plants had started with the onset of agriculture, and gained momentum with organised learning. Competent and invaluable crossing and selection programmes were well underway in the latter part of the 19th century, providing crucial parental material for modern cultivars. After his *On the Origin of Species by Means of Natural Selection* (1859) and *The Variation of Animals and Plants under Domestication* (1868), Charles Darwin (1809-1882) in 1876 had noted that inbreeding usually reduced plant vigour but that crossbreeding restored it, a fact that was confirmed by G. H. Shull in 1908. Rarely cited is the work of Johann Christian Fabricius (1745-1808) the entomologist and economist, who proposed that new species and varieties could arise through hybridisation and by environmental influence on anatomical structure and function. C. Saunders adopted the plant breeding principles of planned crossbreeding, rigorous selection protocols, replicated trials, and checking performance for local use. His work led to the introduction in 1900 of the technologically advanced Canadian wheat cultivar, Marquis. In 1917, D. F. Jones discovered the double-cross hybridisation techniques. By 1921, the first hybrid maize involving inbred lines were sold commercially. In the last 50-60 years, through the rapid development of crop genetics and genetical science, improved strains of rice and wheat led to the Green Revolution, other new hybrid crops were created, genetic engineering was able successfully to produce transgenic plants, and a systematic transfer took place from the original 'crossing two of the best and hoping for the best' approach of breeding and culling by numbers, to rational and sophisticated crossing programmes, careful selection of parents and the systematic introgression of desirable genes. This has enabled robust approaches to combat pests and diseases, and to improve yields and quality characteristics. Several articles in the *SCRI Annual Report* series describe advances in modern plant genetics, breeding, and pathology, as well as more recent discoveries in agricultural environmental science, all underpinned by biotechnological innovations. Parallel advances have been made elsewhere in livestock breeding.

Modern-style pest and disease control through application of such substances as arsenates, Bordeaux mixture (copper sulphate and lime), derris, London Purple, nicotine, paris green, pyrethrum, quassia, and tar oils began in the latter half of the 19th century, aided in the 20th century by new application devices and improved synthetic chemistry. Synthetic pesticides spun out of the discovery in 1942 by P. H. Muller (1899-1965) of the persistent insecticidal properties of dichlorodiphenyltrichloroethane (DDT), a chlorinated organic compound originally synthesised in 1874 by O. Zeidler. Other similar compounds were introduced, such as chlordane (1945), methoxychlor (1945), aldrin (1948), heptachlor (1948), Toxaphene (1948), and endrin (1951). From military research on poison gases in Germany during World War II came the organophosphorus compounds such as Schradan and parathion. Other synthetic compounds were introduced, such as the dithiocarbarnates, the methylthiuram disulfides, thaladimides, and Malathion, and the pesticide industry produced an array of insecticides, herbicides, fungicides, molluscicides, growth regulators, rodent poisons *etc*. In response to concerns about the environmental effects and persistence of pesticides, not least through the publication in 1962 of *Silent Spring* by R. Carson, the efforts of diverse environmental groups, reports of adverse health effects, the development in some instances of pesticide resistance, and the regulatory costs imposed on the agrochemical industry, interest grew in organic farming methods and in integrated control measures (ICM). These involve in various combinations, pest- and disease-resistant cultivars, minimum input systems including ultra-low-volume sprayers with specially formulated low-environmental-impact synthetic pesticides, biological control systems including trapping systems and introduction or boosting numbers of predators, modified rotations, mixed cultivar planting, and careful agronomy. ICM systems have lessened but by no means eliminated the need globally for synthetic pesticides, and many have observed that since the introduction of pesticides there has been a rise globally in life spans and the quality of life.

Economic and social disruption in the 20th century – two World Wars, smaller wars and conflicts, the Great Depression of the 1930s, shorter periods of economic depression, the Cold War, the Great Leap Forward and Cultural Revolution in China, and the collectivist policies of the former Soviet Union – greatly affected global agriculture. Both World Wars provided major fillips to the introduction of scientific agriculture, as did industrialisation and the demands posed by massive population growth. Worldwide, in the first part of the 20th century, there was a phase of setting up research institutes (such as the Scottish Plant Breeding Station in 1921, the predecessor of SCRI), colleges, university departments, agencies, and government departments. Periods of economic depression were associated with protectionist policies, as in the 1930s, with tariffs and non-tariff measures such as the 'milling ration' in which home-grown material had to be used in the grist. After World War II, scientific advances in agriculture and the storage and processing of food, all reinforced by the establishment of various UN agencies, the CGIAR system, the EU, and aid programmes such as the US Marshall Plan, have enabled the stage to be reached of low commodity prices, commodity surpluses, formation of large-scale farm enterprises, and a lessening of the role of the family farm unit, although it still remains the dominant global unit of agricultural and horticultural production. The Green Revolution arose out of US-funded aid programmes to develop new strains of wheat and rice that produced high yields with adequate supplies of water, fertilisers and pesticide treatments.

There are certain characteristics of agriculture that affect and justify public and private investments in its science as well as in the production of agricultural commodities. (a) As a nation's economy expands and evolves, the relative importance and cost of agriculture declines; as incomes increase a smaller fraction of the total resources of the country are required to produce the necessary amount of food for its total population, and rural populations can become economically vulnerable. (b) Most of the populations of poor countries are reliant on agriculture for survival. Agriculture is still the source of livelihood for around 50% of the world's population, but in the MDCs, the figure is much less, despite the fact that agriculture was central to their gaining strong economic positions. (c) The global economy is dependent on international trade in agricultural and food products, and the existence of agricultural surpluses. Few politicians can disregard the social upheaval caused by food shortages. (d) Rural populations have provided the urban workforces needed for economic expansion, people released as a result of improvements in agricultural efficiency. (e) About 10% of Earth's land area is deemed to be arable, about 25% is down to permanent meadows and pastures, and the rest is forested or non-agricultural. With mechanisation, fertilisers, pesticides, improved cultivars, and good agronomy, it has been possible through increased yields to restrict agricultural intrusion into natural habitats despite burgeoning population growth mainly in the LDCs. (f) For farmers and agricultural workers, incomes tend to be unstable and lower than in most other sectors of the economy; farming is constrained by having to predict market demands; agricultural commodities have a low responsiveness to changes in prices; surpluses can soon be produced; erratic effects arise from poor weather, outbreaks of pests and diseases; competition is fierce; and farmers and farm workers rarely benefit from the value-added rewards further up the food chain. Government intervention to maintain incomes has been a feature in both LDCs and MDCs, and comes mainly in the form of direct payments, production quotas, import quotas, import levies (tariffs), and export subsidies, as well as through indirect support measures including veterinary and phytosanitary controls, diversification and development grants, and public-sector-supported R&D. Other factors come to bear on incomes, however, such as the level of general economic growth, competition for educated labour in a technologically challenging age, and access to competition-relevant intellectual property and specific markets. Yet government intervention in agriculture and horticulture has been regarded as a suppressor of the economy. (g) With the exception of collective farming in Communist and like economies, agriculture and agricultural land are essentially in private hands, but there has been a marked trend of transfer from the family farm unit (rented, owned outright, or mortgaged) to large-scale specialist farming run as a business enterprise. Farms as basic units of commercial agricultural and horticultural operation encompass mixed farms that tend to be small-to-medium sized; large, mainly cash-grain crop farms; large stock farms; plantations; and the small to very-small farms in the LDCs. Larger farms are almost invariably the more efficient in all respects. Industries upstream and downstream of agriculture, and the retail sector have also consolidated. (h) The pattern of agriculture dictates the landscape, most cultures are rural-based, and the rural condition and *modus operandi* can assume a greater political importance than its population would imply.

Universal environmental awareness has led to R&D in minimal, no-till, and mulch-tillage agriculture in order to maintain soil structure and limit the consequences of tillage, namely soil erosion, oxidative processes, greenhouse-gas emissions and loss of water by evaporation. Other sustainability issues are balancing inputs and outputs with improved knowledge of crop nutrient needs; the use of animal and green manures, composts, peat, sewage sludges, abattoir wastes, and lime; above-ground and below-ground region-specific biodiversity; the design and establishment of refugia and dispersal corridors (mainly wide headlands and wide and tall hedgerows) for native flora and fauna; curtailing agricultural emissions (greenhouse gases, pollutants, pharmaceuticals *etc.*); and improved water management (protected and semi-protected cropping, irrigation, hydroponics, avoidance of flooding and silt damage, avoidance of salinity problems *etc.*). More refined weather and market forecasts, and monitoring (often remote) of the weather, crop performance, and pest and disease incidence have given rise to effective decision-support systems as an essential modern farming tool. Inadequate attention has given in recent times to crop rotation – the successive cultivation of different crops in a specified order on the same field. In central Africa, 36-year rotations have been reported with a crop of finger millet rotating with a 35-year growth of woody shrubs and trees. In principle, similar systems prevail in the rest of the world where long-lasting perennial plantation crops (*e.g.* raspberries) are rotated with conventional annual or biennial arable crops. Short-term planning in the allocation of research funding has by-passed long-term studies using modern technologies on the impacts of specific crops and their rotations on soil fertility and soil structure.

In concert with modern mathematics, chemistry, physics, computing and information technology, supply-chain management, food and industrial product processing, and satellites, transgenic technology with its hugely innovative potential to address hitherto intractable environmental, human and plant health, quality, and production efficiency issues, is but the latest scientific advance in the progress of global agriculture, horticulture, managed forestry, and the human condition. According to J. S. McLaren of StrathKirn Inc., the next phase of agriculture will be the age of the biorefiner, involving bioprospecting, biomimetics, biocatalysis, biomaterials, and the design and exploitation of organic compounds and products derived from them, and biologically derived energy. This view supported by the recent investment decisions of many major corporations. Many rapidly developing LDCs such as India and China regard modern agriculture as the key to their future economic success, reform, and sustainability.

Types of Agriculture In the MDCs, organic, conventional, and 'biotech' (GMO-based) farming is practiced to varying degrees; in the LDCs, there also remains subsistence or peasant agriculture that confines its practitioners to grinding poverty and little dignity. Organic agriculture in the MDCs operates with a focus on soil fertility, ecological principles, crop rotation, and a belief in the rectitude, sustainability, and biodiversity-enhancing characteristics of its approach and the validity of its rules which preclude synthetic fertilisers, synthetic pesticides and GM crops. Criticisms of the organic model include (a) its inability to validate claims as to the health-enhancing qualities of organic foods, (b) its low productivity compared with conventional and biotech agriculture, (c) dependence on the use of poisonous copper salts, (d) acceptance of blemished produce and the risk of mycotoxins and other antinutritionals as well as reduced vitamin C levels, (e) reliance on faecal fertilisation with consequential concerns about contamination of organic produce by food-poisoning micro-organisms and the eggs of parasitic nematodes as well as concerns about the pollution of water courses, (f) organic farms and holdings acting as repositories of pests and diseases, (g) reliance on tilling leading to damage of soil structure and the release of greenhouse gases, (h) marketing based on (or associated with) criticism of and sometimes scaremongering about conventional and biotech agriculture, (i) reluctance to adopt and suspicion of new scientific and technological advances, although modern breeding systems not involving transgenic organisms, and molecular diagnostics are accepted, (i) the inability of organic farming methods to meet increasing demands on global food supplies without encroachment on natural habitats, (j) the high cost of production compared with conventional and agbiotech systems, and (k) susceptibility of organic produce to competition from fraudulently labelled conventional produce.

Conventional agriculture covers a wide spectrum from the unsustainable to the sustainable. The more advanced conventional systems have adopted new scientific, engineering and technological approaches, and have shown long-term systematic productivity improvements. Conventional farming has met the nutritional needs and demands of a rapidly expanding global population. Criticisms of the conventional model include the following. (a) The reliance on tillage still prevails in most types of conventional agriculture and there is only a slow uptake of no-tillage or minimum tillage systems. (b) Efficiency gains have led to politically embarrassing surpluses even if they have other food-security and trading benefits. (c) An increasing dependence has developed on 'growing' subsidies in the MDCs. (d) Even though the best conventional systems have strict market-related phytosanitary and quality-assurance measures, in the EU there is the concept of agriculture operating with public goods in a multifunctional landscape. Modern conventional agriculture may be regarded as too efficient, reducing seed rain from weeds leading to a depletion of the weed-seed bank and thereby the natural fauna dependent on weeds; as a result there has been a marked contraction in rural biodiversity and visual amenity. Sophisticated machinery currently available to separate weed seed from harvested produce, wide undisturbed headlands, tall and wide multi-species hedgerows, refugia of native plant species, and careful agronomic practices can reverse the decline in biodiversity. (e) A reliance on agrochemicals raises questions about sustainability the quality of produce, and impacts on the environment. (f) Market developments have led to the loss of small mixed farms, considerable rural depopulation (a version of desertification), and the emergence of specialist and ruthless agri-business disconnected from traditional rural communities, contrary to the expectations of urban humanity. Poor broadband access; limited transport, health, and education facilities; and incomers detached from rural attitudes have concerned those wishing to amplify the social and economic well-being of the countryside. (g) A decline has taken place in the political and economic influence and image of conventional agriculture. (h) Organic and subsistence farming have been undermined by the success of conventional farming, and have been deprived of essential R&D. (i) Equivalent to biodiversity-suppressing crop monocultures, industrialised (intensive, high-density) drug-dependent and high-biosecurity livestock production may meet the demand for low-cost, high-volume, high-quality, uniform livestock products, but is out of kilter with the behavioural or experiential welfare needs of the livestock.

Biotech agriculture began in 1996 with the advent of commercial GM crops, creating a new vision for the production, processing and utility of crops and livestock. GM crops encompass strategies to (a) control pests, diseases, and weeds; (b) modify the ability to counteract abiotic and biotic stresses; (c) modify the composition (*e.g.* eliminating allergens and antinutritional factors), shape, colour, size, aroma, texture, taste and yield of crops; (d) generate at low capital costs human-pathogen-free, high-value nutraceuticals and therapeutic agents such as vaccines, antibiotics, enzymes and growth factors, *i.e.* a combination of 'green' and 'red' biotechnology; (e) engineer plants to treat wastes and contaminated land, water and atmospheres (phytoremediation), *i.e.* a combination of 'green' and 'white' biotechnology; (f) produce industrial feedstocks by producing specialist proteins, carbohydrates, lipids, fibres and other cell types, dyes, *etc.*, *i.e.* 'white' biotechnology; (g) create renewable sources of energy through the growing and combustion of biomass and the production of gaseous and liquid biofuels, *i.e.* a combination of 'green' and 'white' biotechnology. New types of diagnostics, accelerated plant breeding (including tree breeding) and mass propagation, phytosanitary systems, and novel soil engineering have arisen from the technologies and concepts that have given rise to transgenic organisms. Criticisms of agbiotech relate to six main points. (a) Organic agriculture as currently ordained and practised cannot co-exist with agbiotech where there is detectable gene flow and co-mingling of GMOs with organic products. Gene flow occurs in all habitats, and conventional plant breeding sets suitable separation distances to reduce or eliminate cross-transfer of genes. That most of all types of agriculture and horticulture in the MDCs, and 60% in LDCs, use species that are alien to the region under cultivation, and that despite billions of meal events in which GM foods have been consumed without any detectable harm to humans or livestock, is of little consequence to organic agriculture where there might be 'alien' genes, even though those genes are natural, and could arise in any case in 'normal' species through natural or isolated mutations or horizontal gene transfer. It is the process of producing transgenics as well as the products that are regarded as unacceptable, and gene flow or contamination would remove the choice of those who wish to grow or consume organic produce. Some have ethical objections, others commercial reasons, sufficient to seek to ban GM crops regionally, nationally, or internationally. There are numerous strategies to curtail gene flow (*e.g.* choice of species, agronomic practices, gene-use restriction technologies *etc.*) (b) At present, until and unless legislation is enacted, there is no legal redress for compensation for loss of organic status by 'contamination' with GM materials. Parenthetically, there is little redress for the spread of pests, diseases, and weeds from traditional farming systems. (c) Political and economic objections arise from the condensation of power in agbiotech in the hands of a few, mainly US, multinational companies that control the intellectual property, licensing and marketing of GM crops. Such objections have been made by several NGOs on behalf of LDCs although most of the gains of GM crops are in the LDCs. (d) The environmental and health effects of GM crops have yet to be unequivocally established. Current GM cultivars would allow for greater intensification of agricultural systems. (e) Hostile attitudes in the EU to GM crops means that farmers in LDCs will have problems in supplying GM commodities to EU markets. (f) Acceptance of GM crops would create difficulties for the continuance of an 'industry' consisting of anti-GM activists, GM regulatory bodies, the GM detection and traceability industry, and certain components of the ethics and risk perception groupings. Certainly, there is now firm evidence of widespread non-sanctioned GM crop cultivation in many LDCs, the result of market pressures and superior crop performance.

Summary There remains a need for comparative life-cycle analysis of all types of agriculture, but the march of innovation, the forces of economic growth, and the demands of the global population will ensure that agriculture will continue to adapt to the opportunities offered in the market place. Risk-aversion in the food-replete regions will suppress but not prevent innovation. The UK deserves its own science road-map for agriculture.

Agriculture is relatively important and becoming more so. Underestimate it at your peril.

Viruses – evolving organisms?

D.J. Robinson

Ever since viruses were first discovered, there has been argument as to whether or not they are organisms. Beijerinck is often considered to be the "father" of virology because in 1898 he correctly interpreted the observation that the agent of tobacco mosaic disease could pass through a sterilizing filter as showing that the agent was fundamentally different from previously known disease-causing micro-organisms. In contrast, Ivanovskii, who had carried out the same experiment as early as 1892, was still arguing in 1903 that the agent was simply a very small bacterium. As knowledge of the properties of viruses grew, it became evident that Beijerinck's view was the correct one. Viruses lack many of the properties that are regarded as characteristic of organisms: viruses are not composed of cells, they have no metabolism, they do not grow (*i.e.* they do not get larger as they get older), and indeed on their own they are lifeless. By 1928, chapters on viruses were appearing in textbooks on colloid chemistry, and the crystallization of tobacco mosaic virus by Stanley in 1935 seemed to many finally to demonstrate that viruses are "merely" chemicals, albeit very complex ones. However, it was also evident that in a suitable host cell, viruses alter the metabolism of that cell, replicate and multiply, and that they have genetic systems that are comparable to those of organisms. Thus by 1937, Delbrück and others had realized that viruses were good model systems in which to study replication and mutation. For pathologists, an important consequence of this organism-like behaviour is that viruses evolve in much the same ways as do organisms.

In this article, I will describe some of the characteristics of virus evolution, using examples drawn from work done at SCRI.

New forms appear

The essential feature of evolution is that new forms appear that have not existed previously. For higher organisms, this occurs over long periods of time, but because viruses replicate very rapidly, recognizably novel forms appear on an observable time scale. Some of the best examples of the appearance of new forms of virus are among the begomoviruses. Viruses in the genus *Begomovirus* infect dicotyledonous plants and are transmitted by the whitefly, *Bemisia tabaci*. Their genomes are circular single-stranded DNA, and most have two genome parts, DNA-A and DNA-B, each of about 2.8 kb. All functions required for replication, control of gene expression and encapsidation are encoded on DNA-A, and genes involved in intra- and intercellular movement are on DNA-B (Fig. 1). Begomoviruses occur worldwide in tropical and warm temperate regions, and cause many diseases of crops and wild plants.

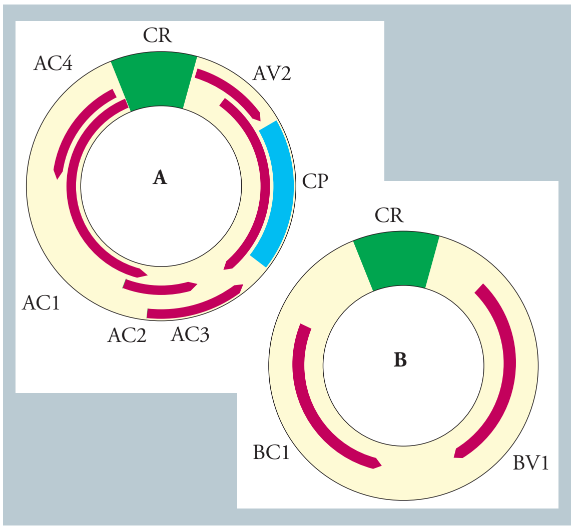

Figure 1 Diagram of the genome of a typical begomovirus. Arrows indicate the positions of genes: CP is the coat protein gene. The region marked in blue is the region derived from ACMV in the recombinant Uganda variant.

Cassava mosaic disease in Uganda. Mosaic diseases of cassava are an important constraint on the production of this staple crop throughout Africa and the Indian sub-continent. We and others have identified five distinct begomovirus species that cause essentially similar diseases: African cassava mosaic virus (ACMV), East African cassava mosaic virus (EACMV), South African cassava mosaic virus, Indian cassava mosaic virus and Sri Lankan cassava mosaic virus. Although earlier work suggested that these viruses each occurred in a different geographical region (see *Annual Report for 1990*, pp.88-90), it is now clear that there is some overlap in their distributions. Thus, in collaboration with workers at IITA, we reported the occurrence of EACMV in Nigeria[1], and more recently showed that all three African viruses occur in Madagascar[2]. However, the most interesting work from an evolutionary point of view centred on Uganda.

Cassava is not a native plant to Africa but was introduced from South America, probably by Portuguese traders and settlers. When it first reached Uganda is unclear, but its presence there was noted by Speke during his expedition in 1875. Until the 1920's it was an unimportant crop, but thereafter its cultivation increased and it is now the main staple in much of the country. Cassava mosaic disease, caused by ACMV, was first recorded in 1928 and subsequently became endemic, although the losses it caused were tolerable. This situation changed from 1988 when an outbreak of severe disease was reported in Luwero district and spread southwards at a rate of 20 km / year, eventually reaching the northern shores of Lake Victoria. In the area affected by the epidemic, which has now spread into all neighbouring countries, cassava yields were virtually nil and people starved.

Workers at SCRI contributed to understanding the causes of this epidemic by characterizing a novel form of begomovirus from cassava affected by the severe disease[3]. This virus, called the Uganda variant (UgV), has a DNA-A that is clearly the product of recombination between the DNA-A's of ACMV and EACMV. Most of the sequence is like that of EACMV but the coat protein gene is like that of ACMV (Fig 1). In both parts, the sequences faithfully match those of the parent viruses, and examination of a range of UgV isolates showed that there was hardly any variation among them. These observations implied that the recombination event that led to the formation of UgV was recent, and that UgV had not yet had time to diversify by the accumulation of mutations. UgV occurred only in the area affected by the epidemic, indicating a causal connection between the new virus and the epidemic. Moreover, in a popular Ugandan cassava variety, UgV reached about 20-fold higher concentration than did an isolate of ACMV typical of those circulating in Uganda before the epidemic. However, the most severe disease appeared in plants infected with both UgV and ACMV[4] (Fig. 2).

UgV is therefore an example of a newly evolved virus with increased pathogenic potential. The key event in its evolution was recombination between the DNA-A's of ACMV and EACMV, which can have taken place only in a cassava plant doubly infected with the two parental viruses. Such double infections are uncommon, and therefore recombination should be a rare event. However, once this particular recombinant had been produced, it was well adapted for transmission by the local strains of whitefly, and therefore it persisted and spread.

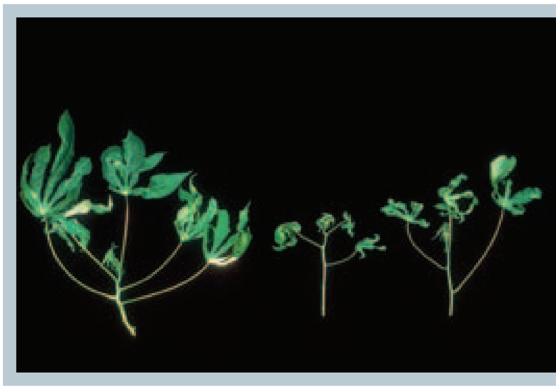

Figure 2 Mosaic-affected cassava shoots: left, infected with ACMV; right, infected with UgV; centre, doubly infected with both ACMV and UgV.

Cotton leaf curl disease in Pakistan. Another example of a disease caused by begomoviruses is leaf curl disease of cotton (Fig. 3), which was first recorded in Pakistan in 1967. The incidence of the disease increased rapidly from 1989, coinciding with the widespread cultivation of S-12, a high-yielding long-staple cultivar that is highly susceptible to infection with cotton leaf curl virus. Another factor in the epidemic was the presence of huge uncontrollable populations of whiteflies that had arisen following the over-use of pesticides and the development of resistance to many of them. By 1993-94, losses of cotton (Pakistan's principal export) were estimated at about 2 million bales, worth around $400 million.

There was a possibility that there might be parallels with the cassava mosaic epidemic in Uganda, but when we examined the DNA-A of viruses in leaf curl-affected cotton, it quickly became clear that the situation was rather different. Instead of a single novel form, we found many different variants[5]. Some included regions whose sequence closely resembled that of parts of the DNA-A of okra yellow vein mosaic virus and thus were obvious recombinants, although the recombinants typically induced leaf curl rather than yellow vein symptoms in okra (Fig. 3). The origin of other variants was less clear. The recent evolution of cotton leaf curl virus in Pakistan had therefore been characterized by an explosion of new variants, perhaps induced by the prevalence of susceptible cotton cultivars and massive populations of the vector. In another contrast with the Ugandan cassava scenario, multiple infections were common in Pakistan. More than half the plants tested contained two or more virus variants[6]. There were therefore plenty of opportunities for recombination to produce new forms, but other processes may also have had a role in their evo-

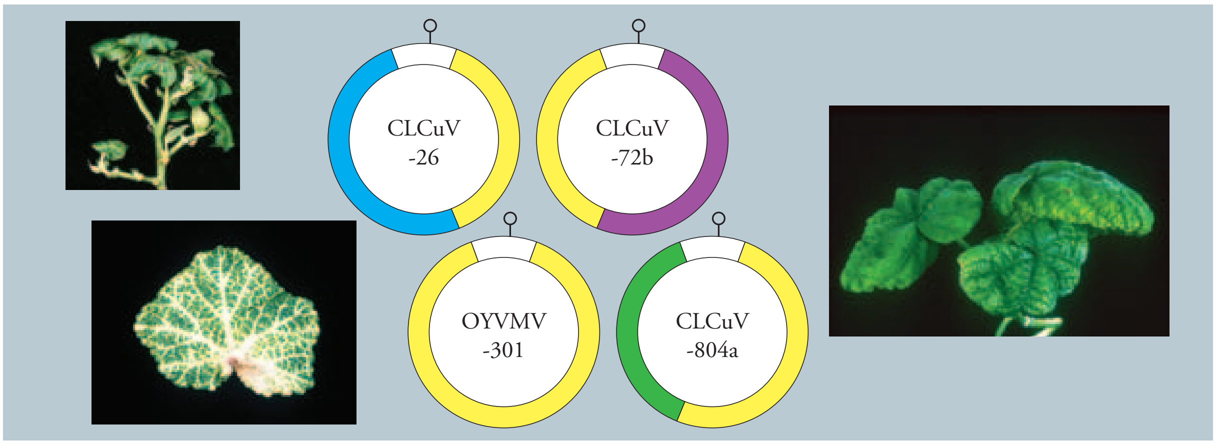

Figure 3 Centre panel: diagrams of the genomes of three recombinant CLCuV variants, showing the regions derived from okra yellow vein mosaic virus (OYVMV) in yellow. Top left: symptoms of CLCuV in cotton. Bottom left: symptoms of OYVMV in okra. Right: symptoms of CLCuV in okra.

lution. As in Uganda, the epidemic was brought under control by the introduction of resistant cultivars. But in Pakistan, the evolutionary pressure was so great that in 2001 a strain of virus appeared that could overcome this resistance, something that has thankfully not yet happened in Uganda.

Evidence of selection pressures

The appearance of new viruses is evidence of the products of evolution, but Darwinian evolution postulates that for new forms to persist they must be well fitted to withstand the selection pressures imposed upon them. For UgV, we can surmise that key factors were its ability to replicate to high concentrations, and its acquisition of the coat protein gene from a local ACMV strain that was presumably already well adapted for transmission by the local whitefly population. In Pakistan it may be that some of the cotton leaf curl virus variants we observed will not survive for long, but that one or two of the best adapted will become dominant. In other cases, the study of patterns of variation among strains of a virus can offer clues to the selection pressures that have operated to bring about the present diversity.

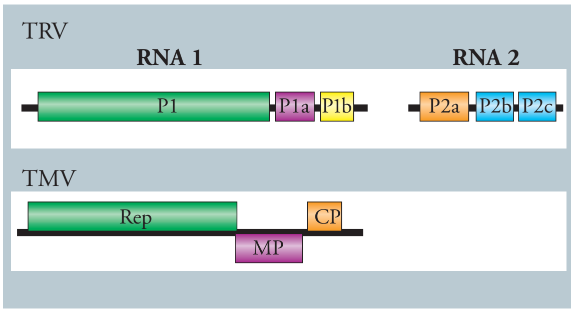

Figure 4 Diagrams of the genomes of tobacco rattle virus (TRV) and tobacco mosaic virus (TMV). Coloured blocks represent genes encoding replication proteins (green), cell-to-cell movement proteins (purple), coat proteins (orange), seed transmission protein (yellow) and nematode transmission proteins (blue).

In contrast to the multiplicity of begomoviruses, the genus *Tobravirus* contains only three species[7]:

Tobacco rattle virus (TRV) occurs in Europe, North America, Japan, China and New Zealand, and infects more than 400 species of monocots and dicots in over 50 families, including many crops and common weeds. It is best known in Britain as one of the causes of spraing disease of potatoes.

Pea early-browning virus (PEBV) occurs in Europe and North Africa, and infects legumes.

Pepper ringspot virus occurs in South America, and causes diseases in peppers, tomatoes and artichokes.

All three viruses are spread by free-living nematodes in the genera *Trichodorus* and *Paratrichodorus* (trichodorids), which are found mainly in light or sandy soils. The genomes of tobraviruses consist of linear single-stranded RNA, and are bipartite. The larger RNA, RNA-1, codes for replication and intercellular movement functions and for a protein involved in seed transmission (Fig. 4). Although there are large differences between the RNA-1 sequences of the three virus species, there is little difference among those of different strains of TRV. In the three TRV strains whose RNA-1 has been completely sequenced, more than 99% of the 6791 bases in RNA-1 are the same in all three. The smaller RNA, RNA-2, encodes the virus coat protein and other proteins involved in transmission by nematodes (Fig. 4), and there are large differences among the RNA-2 sequences of different TRV strains[7].

The variability of the part of RNA-2 that encodes the virus coat protein is reflected in the extreme serological diversity of virus strains; multiple serotypes of both TRV and PEBV are recognized. We also showed that RNA-2 encodes the determinants of nematode transmissibility[8]. At least 10 trichodorid species can act as vectors, and for TRV there is a substantial degree of specificity between vector species and virus serotype[9]. In some instances, the specificity between a single trichodorid species and a single virus serotype seems absolute[10], but in others the correlation is less exact. This probably reflects the involvement of the other RNA-2-encoded genes in nematode transmission[11]. These observations suggest that the reason why tobravirus RNA-2 is so much more variable in sequence than RNA-1 is that this variation represents adaptation for transmission by different species of nematode vector, or even by different populations of a vector species. In this connection, it should be remembered that, unlike viruses with aerial vectors, soil-borne viruses have limited means for long distance dispersal to new sites. Trichodorids probably move laterally no more than 1 m/yr, and tobraviruses therefore have to rely on means such as soil movement or the movement of infected vegetative propagating material or seeds for their long distance spread. Tobravirus populations are thus effectively evolving in isolation from each other. In these circumstances, properties such as efficient transmission by the local trichodorid population and a wide host range have obvious value for survival.

The diversity of viruses

From examples such as those discussed above, it is clear that evolution driven by natural selection can account for the present day diversification of viruses and for the diversity found within genera and species. When the scope is widened however, the arguments become more speculative. One might ask, for example, why the tobravirus genome is in two parts. Here, it is instructive to compare the tobravirus genome with that of tobacco mosaic virus (TMV), a virus with perhaps the simplest genome of all, consisting of only a single piece of RNA. The TMV genome encodes only four gene products: two proteins involved in RNA replication, a cell-to-cell movement protein and a coat protein (Fig. 4). Tobraviruses have analogues of each of these gene products, which bear sufficient similarities to the TMV proteins to suggest that they have a common origin. The tobravirus genome also encodes three additional proteins: one involved in transmission through seeds and two involved in transmission by nematodes. There are no clues as to the origins of these additional genes, but it seems likely that a common ancestor of TMV and tobraviruses acquired them and subsequently evolved into the tobraviruses. What was the selection pressure that drove this augmented genome to divide into two parts? One possibility is that with the additional genes it was too large for efficient replication. RNA replication is relatively error prone, and as an RNA gets larger the probability of producing an error-free copy falls off rapidly. Another possibility is that hiving off the genes involved in nematode transmission into a separate piece of RNA facilitated their rapid adaptation to different vector populations.

The functions of RNA replication, cell-to-cell movement and coat protein provided by the TMV genome are the minimum set of functions required by an autonomous RNA plant virus. Coat proteins though are multi-functional. They not only protect virus RNA from degradation, but are usually required for plant-to-plant transmission by vectors and for systemic movement of virus through the vascular system of an infected plant. However, a few plant viruses, notably the umbraviruses, do not have a coat protein gene[12]. Umbraviruses use the coat protein of a helper virus to encapsidate their RNA for plant-to-plant transmission by aphids, and thus can only be transmitted from plants that are doubly infected by the umbravirus and the helper. Umbravirus genomes do contain genes encoding RNA replication and cell-to-cell movement proteins, and also include a gene known as ORF3 (Fig. 5), whose protein product provides some of the other functions of a coat protein. Thus the ORF3 protein forms nucleoprotein particles with the virus RNA[13] (Fig. 5), protects the RNA from degradation, and mediates its transport through the phloem[14]. One might speculate that the ORF3 protein is a proto-coat protein in the course of evolution, which has yet to develop the ability to form conventional virus particles and mediate vector transmission. Alternatively, it could be a relic of a fully functional coat protein that has lost its particle formation and vector transmission functions after the virus acquired the ability to use a helper virus protein for these purposes. Of course, neither of these ideas might be correct, and they may merely reflect the prejudice of a

a)
b)

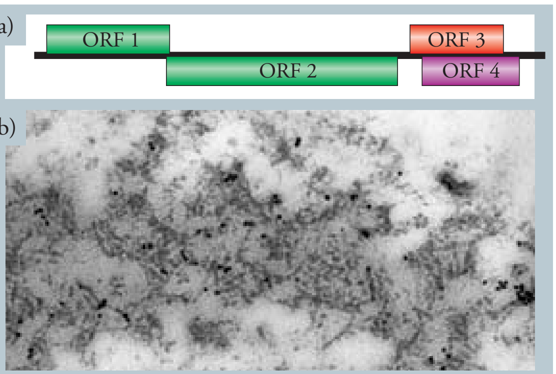

Figure 5 a) Diagram of the genome of an umbravirus. Coloured blocks represent genes encoding replication proteins (green), cell-to-cell movement protein (purple) and ORF3 protein (red). b) Electron micrograph of nucleoprotein filaments containing ORF3 protein and viral RNA in the cytoplasm of an infected cell.

virologist that it is "normal" for a virus to have a coat protein. Moreover, it is difficult to see how they could be tested experimentally.

Although this kind of speculation about the origins of the many types of virus that now exist is an interesting intellectual exercise, it is of little relevance to practical problems of virus pathology. There may be no conclusive answer to the question whether or not a virus is an organism; indeed, as Professor Joad might have said, it all depends what you mean by an organism. But for many purposes, they can be treated as if they were organisms. In particular, the appearance of new variants and the forces that drive these changes seem to follow the same evolutionary models as apply to conventional organisms. If they were pressed on more philosophical questions though, most virologist would simply go along with Lwoff's dictum that "Viruses are viruses".

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Barley Crop Development

R.P. Ellis

Introduction George Mackay described the changes to the SCRI programme since the mid-1970s[1]. These comments apply to barley research so this review can focus on scientific and technical developments in the barley crop. There have been several short reports in the SCRI Annual Report the but the last full report on the barley programme was in the 1978/9 SPBS Annual Report[2]. Since then knowledge of the crop, it origins, breeding methodology, and genetical research have advanced out of all recognition. In particular the development of DNA based technologies have revolutionised biology. However, despite specific examples of the application of marker-assisted selection[3], the full impact of modern genetic technology on barley breeding is yet to be realised. Marker assisted backcross conversion offers a more certain technique for the introduction of novel alleles into cultivars than the simple backcross technique used to move the high amylose character from Glacier to adapted cultivars[2]. The current updating of the International Treaty on Plant Genetic Resources, which emphasises the use of germplasm, highlights the possibility of breeding new cultivars with useful traits from landraces, illustrated below in relation to Scots Bere.

Origin – use of wild barley? Barley, as a crop, originated in the Fertile Crescent and became a successor crop to wheat because of its greater tolerance to the soil salinity, accidentally induced by irrigation[4]. The main uses of barley are for animal feed and beverage production. As the processes of domestication[5] were succeeded in turn by 'involuntary' breeding, to produce landraces, and then by deliberate breeding, to give highly bred cultivars, so characteristic traits of wild barley were lost. A large body of work has developed based on the use of disease resistance[6] and the wider genetic variation in wild barley for cultivar improvement[7]. The SCRI programme explored the use of mildew resistance from wild barley[8] in a backcross programme that produced resistant lines. Even although these genotypes were later tested in Egypt, Morocco and Tunisia in an EU funded project[9] they did not achieve commercially acceptable performance. If a market in pre-bred lines existed in the UK then they could have made an impact after re-crossing to more advanced materials within a commercial programme.

Other examples of work with wild barley at SCRI concerned the improvement of tolerance to physiological stress. A useful discovery was of the stable isotopic changes related to stress reactions through avoidance rather than tolerance[10]. Drought avoidance is enhanced by the development of high levels of post harvest dormancy[11] but this trait can be problematic for *ex situ* collections. The largest collection of wild barley is the BBSRC collection (some 25,000 samples) held at the John Innes Centre (JIC). Professors Hayes (Welsh Plant Breeding Station) and Dinoor (Hebrew University of Jerusalem) jointly organised the collection of 230 Israeli populations in 1977. The original seed material was jointly multiplied, on a single plant basis, in the UK by workers at PBI, Cambridge, SPBS and WPBS and then deposited in a high quality seed store at PBI and later moved to JIC. When samples were tested in 1999, following a recent multiplication cycle at JIC, dormancy was found in all samples and germination ranged from 0% to 80%. This effect relates to the interaction of the genotypes with the glasshouse environment. In Northern Europe the abiotic stresses tend to be at lower levels than those in the Middle East and are less predictable e.g. rainfall does not follow any seasonal pattern. So in this context high post-harvest dormancy does not have any adaptive significance and is antagonistic to good malting quality. The use of wild barley accesses the wide genetic diversity between wild and cultivated barley parents but requires a more rigorous selection programme than cultivar inter-crosses, perhaps providing an opportunity for marker assisted selection in early generations to eliminate the undesirable characters of wild barley.

Landraces – not wild barley! It is however, interesting that perhaps the most important single gene for Northern European barley growers, the *mlo* mildew resistance, was discovered in Ethiopian Landraces rather than wild barley[12]. Landraces are genetically closer to modern cultivars than wild barley but even so extensive breeding was necessary to assemble favourable alleles in appropriate linkage blocks[13]. Landraces existed worldwide and still represent a source of useful alleles closer to cultivars than wild barley. An interesting example is the tolerance of acid soils through limited uptake of heavy metals (Al, Fe, Mn) into the cytoplasm (Fig. 1). Barley is less tolerant of acid soils than wheat or oats so a major transformation of Scottish soils, by the practice of liming, started as barley crops replaced Scots Bere, a Scottish Landrace, particularly in the 19th and early 20th century. It would be possible to reduce the costs of liming if barley were as tolerant as other crops but at the risk of increasing the aluminium content of animal diets.

Figure 1 Trial plots grown on 'reclaimed' woodland. The rectangles enclose; red Golden Promise, green Scots Bere, blue oats and yellow woodland/arable contrast.

The impact of the historical changes are encapsulated in Fig. 1 where in 1978 trial plots were established on soil that was still highly acidic despite liming after the removal of woodland. Golden Promise was highly susceptible and few seedlings survived; in contrast Scots Bere was more tolerant and produced a grain yield equivalent to 1 t/ha. Oats surrounding the trial grew well and produced a higher yield. The overall impression of the site was that high inputs were necessary to produce economically acceptable grain yield at the expense of overall biodiversity. The trial plots resemble a desert while the mixed woodland (oak, birch, pine) hosted a range of plant and animal species. The 'desert' feel of the site was emphasised by the removal of stones from the soil, a common feature leading to the degradation of Mediterranean soils[14]. Stones protect the soil surface from rain induced erosion and act as 'magnets' for moisture with the consequence that individual plants may escape the effect of soil acidity because their roots encase stones.

Figure 2 A small plot trial with Golden Promise (left) grown alongside Scots Bere.

Given that modern agriculture is based on high inputs to give high output, Fig. 2 illustrates a more realistic scenario than Fig. 1 as the application of fertilizer, herbicide and fungicide permits higher and more reliable yields from Golden Promise than Scots Bere. Golden Promise with short straw is well suited to combine harvesting and has small grain that germi-

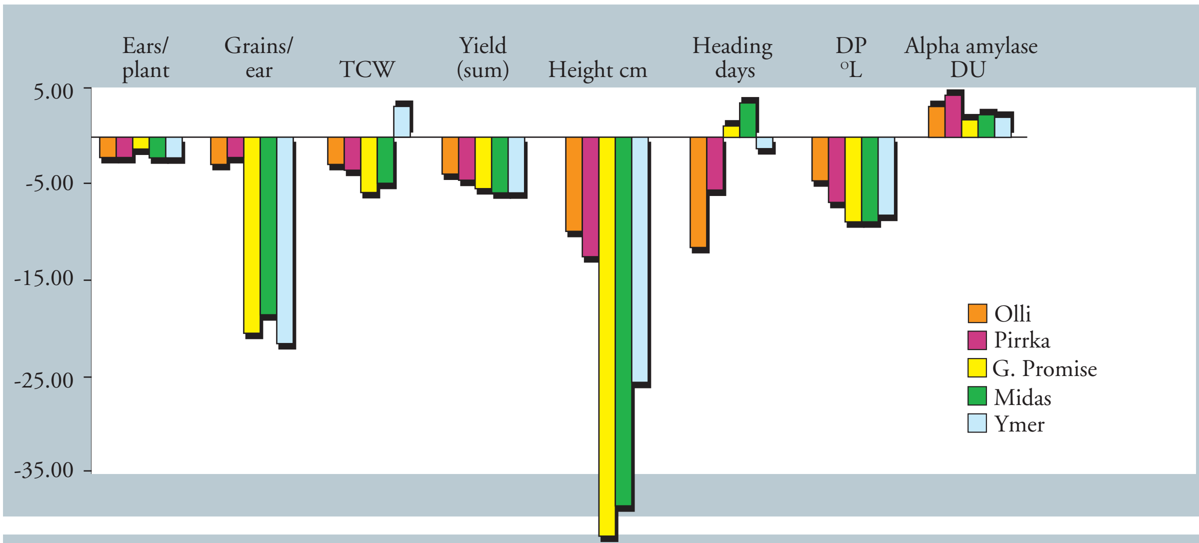

Figure 3 Performance of two six-row (Olli, Pirkka) and three two-row cultivars relative to the base line of Scots Bere's performance [17, 18, 19].

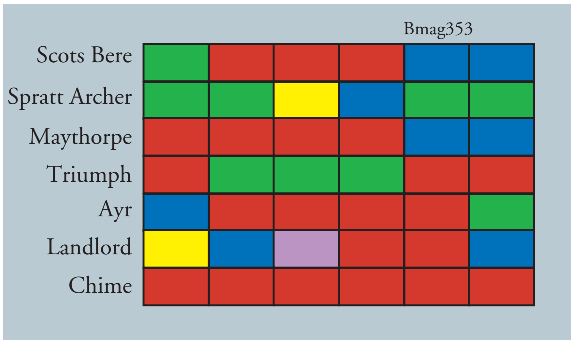

Figure 4 4 SSR alleles at six loci on chromosome 4H. The alleles are colour coded to indicate their frequency (red = high; violet = low) in European germplasm.

nates very evenly in maltings. In particular, the weak straw of Scots Bere (lodging lowers yield) obscures the merits of this landrace. This is well illustrated by the results from a large diallel experiment carried out at the SPBS in the early 1970s (Fig. 3). Scots Bere, Golden Promise and Ymer are adapted to Scotland but are not as excessively early to heading as Olli and Pirkka. Scots Bere was tallest, its straw being 40cm longer than Golden Promise, and was the highest yielding line when the yield components (Ears/m^{-1}, Grains/ear, TCW) were summed. This apparent contradiction of historical experience means that these results should be treated with caution. The results of carefully designed experiments, while accurate, may not be repeatable under normal field conditions.

An additional point of interest is that Scots Bere had the highest level of diastatic power despite having lower alpha-amylase. Diastatic power is the sum of the starch degrading enzyme activity in the malt and is made up of limit dextrinase, alpha-amylase and beta-amylase components. Alpha-amylase is synthesised *de novo* in the aleurone layer in response to a gibberellic acid signal from the embryo at the start of germination. In contrast, beta-amylase is synthesised during grain development and so is a component of the albumin proteins of the grain. Albumins have a higher content of the amino acid lysine than the hordeins, the major storage proteins of the grain. High beta-amylase has the corollary of higher grain lysine content in the endosperm. If re-investigation confirms these results then a major objective, of improving grain nutritional quality, could finally be achieved[15, 16]. It is important to ensure that yield and grain components are compared under carefully controlled conditions, as high grain nitrogen may be simply the corollary of low yield. An appropriate experimental design involves the generation of random inbred lines from a cross between Scots Bere and a modern cultivar and this process has been started.

The development of single sequence repeats (SSRs) in barley[20] sped up the mapping phenotypic traits[21]. In a particularly useful exercise, a range of germplasm (some 900 genotypes) have been scanned for 50 SSRs chosen to give a stratified sample of the genome[22]. The allelic variation (Fig. 4) for the SSRs[23] on chromosome 4H showed a number of unique alleles linked to the genetic factor, mapped to chromosome 4H with morphological markers[24], responsible for acid soil tolerance. Subsequent work[25] in Australia indicated close linkage between *alt,* the gene responsible for acid soil tolerance, and the SSR Bmag353. So, provided that the relative level of tolerance of cross parents is known, selection for Bmag353 can be used in cultivar improvement.

Cultivar breeding Barley cultivars are inbred, although in Scotland levels of out crossing as high as 5% have been observed[26] i.e. the equivalent of or higher than the levels seen in wild barley[27]. Single plant selection was the method used in breeding barley even before the re-discovery of Mendelian genetics by de Vries[28] in 1900. This method was used for example in the development of Chevallier[29], a cultivar that dominated the 19th century English market[30] for malting barley. The intensification of agriculture in the mid-1920s led to the development of breeding programmes to produce varieties bred specifically for malting quality with selection by micromalting[31]. In retrospect the release of Proctor in 1953 by the Plant Breeding Institute, Cambridge was an important prelude to the development of commercial barley breeding in the UK. Commercial breeding became practical after the enactment of the Plant Variety Rights Act in 1964 enabled breeders to earn royalties from certified seed crops. The Plant Variety Rights Act established two hurdles for the breeder; the need to demonstrate the new cultivar was distinct, uniform and stable (DUS) and that it had a useful improvement in performance i.e. value for cultivation and use (VCU). When these tests were satisfied the cultivar could be added to the National List and traded, but in practice little seed was sold unless the cultivar was also added to the UK Recommended List (originally the Recommended Lists of the National Institute of Agricultural Botany (NIAB) and Scottish Agricultural Colleges (SAC)). Relatively few spring barley varieties persisted on Recommended Lists for longer than twelve years (including Proctor, Golden Promise, Midas, Atem, Triumph).

Year	Total cultivars on RL	Cultivar	Yield (Untreated)	Malting Quality	Mildew resistance	Maturity
1983	12	Tweed	2	*	1	4
1984	12	Tweed	3	Good	1	7
1985	14	Tweed	5	Good	1	5
		Heriot	5	Good	4	8
1986	14	Tweed	9	Good	5	6
		Heriot	8	Good	9	9
1987	14	Tweed	10	Good	3	4
		Heriot	9	Good	8	10
1988	12	Tyne	2	*	1	1
1989	11	Tyne	1	Medium	1	1
1990	9	Tyne	1	Medium	1	1
1991	9	Tyne	2	Medium	1	1
1992	9	Tyne	4	Medium	3	1
1993	10	Tyne	7	Medium	6	1
1994	14	Tyne	11	Medium	8	1
1995	14	Tyne	12	Poor	6	1
1996	12	Tyne	12	Poor	5	1
1997	9	Tyne	8	Poor	6	1
		Optic	2	Good	6	9

Table 1 Ranks for selected traits reported on SAC Recommended Lists for Heriot, Tweed and Tyne. Optic figures from the 1997 SAC Recommended Lists are included for comparison.

The early history of commercial barley breeding in the UK involved the formation of agency relationships with established seed houses in Continental Europe. This provided a revenue stream to finance the development of in-house varieties. Among the first 'commercially bred' varieties to be marketed in the UK were; Deba Abed (NIAB RL 1965-74, bred by Abed in Denmark), Zephyr (NIAB RL 1966-76, bred by MGH in the Netherlands) and Julia (NIAB RL 1969-78, bred by Cebeco in the Netherlands). These were all general purpose or feed varieties in contrast to the UK bred malting varieties Golden Promise (SAC RL 1968-1990, bred by Milns Masters, Chester) and Ark Royal (NIAB RL 1976-82, bred by Rothwell Plant Breeders in Lincolnshire). In turn, these malting barleys were outclassed by Triumph (Trumpf) (SAC RL 1980-1991, bred by VEB in the German Democratic Republic). Retrospective genetic analysis[32] showed how UK breeding programmes developed around core varieties in succession resulting in cohorts derived from Vada, Proctor, and Triumph.

In this background barley breeding started at the Scottish Plant Breeding Station in 1968[33]. Within ten years a general malting quality remit replaced the more specialist high diastase and high amylose programmes[2] that were aimed at the whisky industry. A number of cultivars[34] were added to the National List and Tweed (1983), Heriot (1985) and Tyne (1988) were added to the SAC Recommended List. The SCRI programmes aimed to select lines that had good expression of traits suited to both the farmer and grain processors. All were semi-dwarf (Tweed and Heriot with the semi-prostrate *sdw1* gene and Tyne with the erectoid *ari-e*.GP gene), had stiff straw, high yield, good disease resistance and good level of malting potential (Table 1). Tyne received a Medium rating for malting quality, the same rating as Golden Promise, until 1995 when more attention was paid to levels of germinal nitriles. Epiheterodendrin[35] occurs naturally in barley and acts as an anti-feeding defence because cyanide is created when it is digested by grazers such as slugs and rabbits. In whisky distillation epiheterodendrin can be converted into ethyl carbamate, a highly carcinogenic compound. The most practical control is to malt only varieties with low epiheterodendrin and this has been the practise of the Scottish Whisky Industry since the problem was defined[36]. Despite these faults Tyne provided a unique combination of yield, earliness and disease resistance that made it one of the most successful cultivars produced by UK publicly funded barley breeding programmes since the introduction of Proctor.

The significance of public sector involvement in barley breeding was not just development of distinctive cultivars but also an examination the problems of plant breeding from a scientific viewpoint. The use of flexible trial designs[37], obviating the high level of replication inherent in lattice square designs, and the practicality of row and column analysis[38] were both investigated in the SCRI barley programme. The results were published so the implementation of these innovations vastly improved the efficiency of UK barley breeding. Work at SCRI and BioSS indicated how well breeders' trials and National List results could be reconciled[34]. In turn, at the top end of a breeding programme, at the point of entry into National List Trials, it was established that the most serious problem is ensuring DUS criteria are met within a breeder's own programme[33]. The combined effect of the industry wide implementation of technical improvements, the development of new germplasm and the efficiency of National List Trials[40] was the sustained improvement of crop performance (Figure 5.).

Research in genetics[41, 42, 43] and plant physiology[44, 45, 46] at SCRI informed the choice of parents and selection strategies. Visits by and to colleagues in Europe, Australasia and North America were particularly informative. For example the crossing strategy used in the production of Tyne was similar to that

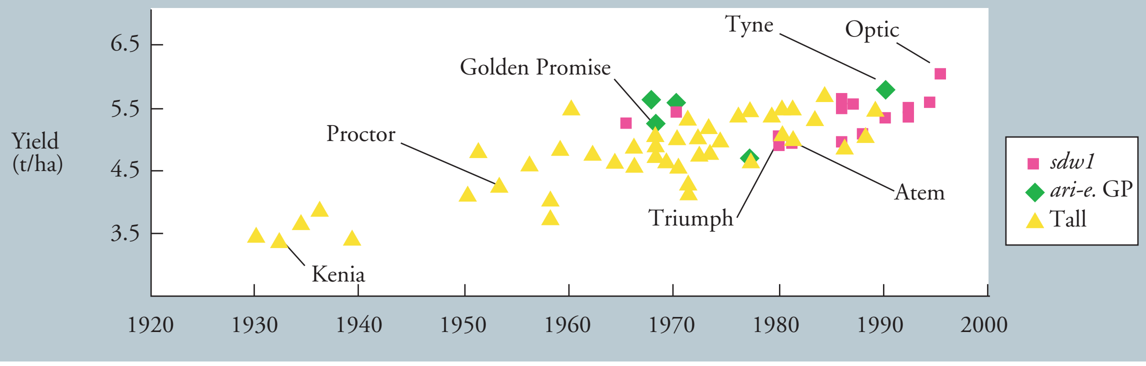

Figure 5 Progress in yield potential related to date of cultivar Recommendation. Estimated from trials grown at SCRI. Note the continued improvement of yield potential despite the use of dwarfing genes.

used in New Zealand to ensure limited recombination within an adapted gene pool. Contrasting parents containing desirable alleles for early maturity (Goldmarker), stiff straw and large grain size (Athos) and good disease resistance (Magnum) were crossed pair wise and then the F_1 re-crossed to give a four-way F_1 (Goldmarker x Athos) x (Goldmarker x Magnum). A particularly large F_3 was raised so that recombinants of parallel ear type could be selected.

The history of barley breeding can be viewed as a contrast between the relative ease in the production of high yielding but poorer quality lines and the additional complication of malting quality selection that reduces the rate of progress for yield. Proctor was out yielded by feed types such as Deba Abed, Julia, Vada, Armelle and Georgie but was the only contemporary choice for a malting quality crop. Maltsters paid a higher price to farmers to compensate for this lower yield potential. The introduction of Triumph overcame the yield differential within spring barley but by the 1970s the high yielding feed crop was actually winter barley, opening a 20% yield differential between the best malting and feed cultivars[48]. Hence the target of breeding a high yielding, good malting quality winter barley is very attractive and could be achieved by converting a spring barley to winter habit or by improving the malting quality of winter types. A crossing programme at Mylnefield attempted to meet these objectives but crosses between spring malting quality and winter cultivars resulted in too high a proportion of lines with a high susceptibility to *Rhynchosporium secalis*. Crosses aimed at converting winter barley to the highest level of malting quality resulted in lines that had high grain nitrogen, resulting from rapid uptake during seedling growth, and so lower hot water extract. Several cycles of crossing resulted in lines with that showed promise but the then available route to commercialisation was suboptimal. There were major handicaps in running a Scottish based winter barley programme, for example the short time between harvest and sowing limited the size of the programme while the absence of regional trialling limited the efficiency of selection. A possible 'technical fix' through the implementation of doubled haploids via anther culture[49] was unsuccessful because the response varied too widely between crosses. The challenge of high malting quality winter barley for Scotland remains to be resolved, especially in the light of changing views on the environmental impact of autumn sown versus spring sown crops.

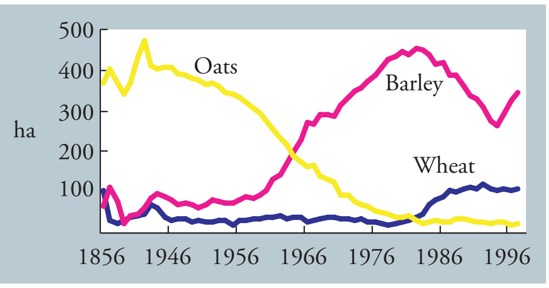

Figure 6 Trends in Scottish cereal crop areas since 1856.

Importance and Future of the Barley Crop

Internationally, barley is still a major small grain crop, albeit less profitable than wheat or maize, that has a particular niche in Scotland. This niche aspect of the crop has an inherent danger as commercial companies need to maximise their return on capital by breeding and marketing over a wide range of environments. In the United Kingdom oats are another example of a niche market. As profitability for breeders and farmers has fallen so the number of entries into NLT has fallen. Long term trends are often difficult to perceive on a year to year basis and so it is difficult to identify the need for appropriate scientific, technical and economic support. The trends for Scottish Crops (Fig. 6.) over the last 150 years indicate that steady decline over a long period can result in the virtual extinction of even the major regional crop such as oats. The best time to seek alternative crop uses for barley, even for outlandish possibilities such as alcohol production for transport, is now, while there is time to consider the complexity of changes to highly developed systems. If barley growing in Scotland were to be restricted, for example by environmental restraints, then it may not be possible for farming to recover sufficiently when greater production is required.

The history of the barley crop indicates how farmers, breeders and processors have been able to respond to contemporary challenges. New genetical methods, including transformation with genes from other species and cross species genomic comparisons will allow precise analysis of the barley genome and enhance the capability of barley for a wider range of end users. The controversy and public disquiet over genetically manipulated crops has obscured the steady progress made by conventional breeding programmes in response to new challenges such as Ramularia/physiological spotting. Improved genetic mapping will enable marker assisted selection[50] to provide a rapid route to the continued improvement of quality and yield performance. The development of a Product Improvement Centre at SCRI will ensure that research effort if focussed into market deliverable products. Collaboration between publicly funded researchers and private industry, a long term theme of SCRI barley research, is a particular UK strength with the potential to ensure appropriate cultivars are available to farmers and the malting industry. It is particularly timely to seek out and conserve the remnants of landraces before they finally disappear from cultivation. A comprehensive genetic analysis of these landraces will resolve the novel allelic content and value of these genetic resources. Investigations of this type will be promoted under the auspices of the Global Conservation Trust envisaged by the International Plant Genetic Resources Institute, Rome[51]. In the UK the current situation where the main research programme on barley and the gene bank are 'divorced' must be resolved.

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Some personal remarks on the Farm Scale Evaluations of GMHT crops

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The continued increase in the yield of crops during the 20th century was not without effect on other organisms of the field. The move from spring-sown to autumn-sown cereals in the 1970s had claimed a large fraction of the annual solar energy, while the increase in number, type and broadening specificity of herbicides had even further reduced variety and abundance in the primary producers. By the late 1990s, many informed commentators felt things had gone too far. Long-term resident species were being lost from vice-counties and animals high in the food chain were declining. Definitive experimental evidence relating cause to effect was difficult to collect at the landscape-scale, but the consensus was that too many fields had become much degraded as biological systems[1, 2], to the extent that continued depletion of diversity must lead to major loss of function in soils.

The ecological debate in the 1990s was about rehabilitating and sustaining the functioning of fields with whatever form of cropping was used. At this time, seed companies notified their intent to commercialise GM herbicide-tolerant (GMHT) crops in the UK. The response had ethical and geopolitical as well as ecological overtones[3]. Arguments on ecological benefit or harm centred on change in pesticide profile, the effect of the GMHT package - the crop variety and herbicide – on the declining, in-field biodiversity and the movement of GM traits into other plants. Purely ecological concerns were raised by English Nature, the Royal Society for the Protection of Birds and concerned ecologists, who felt GMHT cropping used during the 'breaks' between cereals might be a step too far. The break crops, of which oilseed rape was the most widespread, gave probably the last general opportunity for broadleaved weeds to regenerate their populations, which in turn diversified the food web and sustained functions beyond those of the crop plants. In response to these calls, the UK government, through what was to become Defra, asked for tenders for research to examine the effect on farmland biodiversity of GMHT cropping. SCRI joined the Centre for Ecology and Hydrology (CEH) and Rothamsted Research as a bidding consortium. We won and began work in April 1999. The research consortium had to maintain its independence as part of a larger grouping of farmers, seed and agrochemical companies, a Steering Committee and government departments[4, 5].

Methods and experimental design No ecological studies of harm and benefit had been done at a large scale in countries where GMHT had already been grown, but plot-scale comparisons in the UK and overseas all pointed to very small or negligible ecological effects of plants having the GM herbicide-tolerant trait itself [6]. Any ecological impact would likely be through the package of the GM plant and a herbicide (glyphosate or glufosinate ammonium) which was able to target larger and more mature weeds growing when the crop was well developed. It could kill the weeds other herbicides could not reach. It was essential to compare this package with the existing, widespread form of cropping. The comparison was therefore between GMHT cropping as recommended by the manufacturers and the conventional ways of growing the beet, maize or oilseed rape[6]. The experiment was unique in that it would work with the variability among sites and years and not try to constrain it. Having argued that experimenters should be more prepared to relax the boundaries of their system[7], here was a chance to for me work with a group that expressly wished to probe an open system, not just some of its parts in isolation. The greatest challenge nevertheless was whether the comparison could be made successfully - whether a consistent shift, or absence of one, in populations or biological mass could be detected above the noise of weather and the general unpredictability of arable cropping.

In the first year, 1999, an extensive review, re-analysis of past data and collection of specific new information led us to propose a split-field experimental design and the need to repeat the comparison at 60-75 sites to detect an effect above the noise[8]. The statisticians Joe Perry and Peter Rothery led this phase of the work, but the whole team was convinced. The design withstood scrutiny by the Steering Committee and was eventually formalised and made public through the Defra web site. It became the target of anyone with a case against GM field trials. You would share a public debate with a partizan or political activist, who would open with 'I'm no statistician but ....'. Such was the temporary success of this campaign that even some professionals you would meet followed the reluctant handshake with a 'pity about the experimental design'. But our conviction was and is still unswayable – based on the most thorough analysis of arable populations – the design was the best for the purpose, and our rationale was proved correct.

The comparison for the spring-sown beet, maize and oilseed rape was made in the seasons of 2000, 2001 and 2002. The consortium's research centres had access to all parts of GB and shared taking the measurements at sites. Les Firbank and the team at CEH Merlewood coordinated the study, mainly through a dedicated web site and many meetings of the group, while certain tasks, in taxonomy for instance, were allotted to specialists in the consortium. The main effort fell to a group of post-doctoral researchers, whose great ecological strengths were matched by their ability to drive and integrate our activities among all the target organisms, the four types of crop and the varied habitats in which the work was done. The final field measurements were made around September 2002, and the massive collection of data double-punched, checked and audited late that year. The work had become the most comprehensive study anywhere of the cropped habitat. Papers were reviewed by the Steering Committee, sent early in 2003 for peer review to a scientific journal - *Philosophical Transactions of the Royal Society, London* - and published in October 2003[9].

First results The results for the spring-sown crops were clear. If farming used the technology as the companies recommended in the FSE, the last common refuge for in-field arable plants would be accessible to broad-spectrum herbicides. In beet and spring oilseed rape, this would accelerate the decline in arable biodiversity; in maize it would impede the decline, because the existing herbicides – the triazines – were already so effective. The precise results depended on <u>when</u> herbicide and competition affected the extended flush of emergence that began after sowing and decelerated as the crop developed. In conventional crops, the herbicides were given mostly near sowing and got rid of the peak of emergence but not generally the later population, which would then grow to plants of moderate size, mostly below the crop canopy, but still capable of re-seeding. In beet and oilseed rape, GMHT knocked out this later population. Any plants that survived, or germinated even later in the crop, were smaller at harvest and produced no or less seed. The reverse was true of maize, but whether this will hold when the triazine herbicides are no longer used is the subject of further study.

The most general lesson from the FSE is that measurements systematically targeted and applied can detect shifts in the food web caused by change in crop variety or management. Equally instructive was that the primary effect on the weed flora was transmitted to primary consumers, the herbivores and detritus feeders, and their consumers[10]. The FSE was unique in examining and detecting such changes on a large scale before a technology was deployed commercially. The published papers stressed that the effects of GMHT cropping were small compared to the difference in biodiversity between the crop species, and that the overall impact of GMHT cropping on food webs would depend on the rotation, the landscape and other changes in management. Proponents of the technology said that other field practice could readily change to compensate, or that using GMHT crops could lessen or reverse intensification in other parts of the cropping cycle. That may be, but such a contention could not be examined by hypothesis-driven experiment. Nor does recent history support the view that farming is likely to compensate voluntarily to balance the requirements of yield and food webs. 'Winter' cropping was adopted over most of GB, as were the many new types of herbicide and their increasing usage. More likely is that a cheap and effective remedy would be used to despatch the last remnants of the weed flora. Except in a few pockets, the decline of the in-field food web would accelerate. This notwithstanding, matters of predictive up-scaling are as important as the primary result and are still being examined.

GMOs in the environment The FSE also heightened attention on geneflow and the persistence of crop-derived traits in the field. This mattered most for oilseed rape, which persists as seed in fields and waysides, and is outcrossing, so exchanges genes over distance. Two main issues had to be resolved – the movement of genes from a crop to a feral or wild relative (e.g. herbicide tolerance in a weed population) and the occurrence of a GM trait in seed as an impurity in yield.

Comprehensive studies of cross pollination and its effects are rare over large scales in rural environments. From exploratory research in the UK, some biotechnologist and policy advisers had tended to understate, and some activists to overstate, the distance that pollen moves and the time seeds and populations persist in the soil. Hard facts from realistic environments were needed to inform the debate and SCRI was able to provide these through combining its expertise in genetics, statistics, physiology and modelling. By the mid-1990s, SCRI had established itself in this area through competitive contracts on the transmission and persistence of genetic material in oilseed rape. Our approach was to measure the decline of the pollen and seed over distance and time and report the results without favouring any particular stance. Notably, the recent comprehensive studies of geneflow by Gavin Ramsay and Caroline Thompson have set standards in regional or large-scale estimates[11]. It was necessary in this work to establish a zero-point (for example, the distance from a large pollen source at which no geneflow is detected) in order to be able to confirm that low frequencies of pollination were in fact real (and not false positives). However, a zero point was not found even after several kilometres, and it is likely that zero cross-pollination (one field to another) will be rare among oilseed rape fields in the arable regions of the UK. Despite careful wording in reports to emphasise the uncertainties in measuring rare events, it is inevitable that some of the press and various protagonists will latch on to particular distances and persistence times and display them out of context. SCRI's uncompromising stance has nevertheless been appreciated by serious commentators. In response to results in the mid-1990s, the MP and writer on science, Tam Dalyell, asked whether a particular enquiry had taken account of the long-distance outcrossing found by SCRI. Our more recent studies are influencing debate and legislation in the UK and Europe.

The persistence of oilseed rape as seed and feral populations will probably have more effect and consequences than will outcrossing through pollination. The rise of oilseed rape as a break crop since the 1970s is providing a rare opportunity to observe these new genotypes and phenotypes entering and diversifying in a cropped habitat. Even in winter here, feral seedlings emerge and second-year plants flower and fruit in local field-margins and waysides, in contrast to those established Cruciferae of similar architecture, *Sinapis* and *Sisymbrium*, that usually stay dormant for the winter. That feral oilseed rape can persist over ten years in disturbed habitats and waysides should not now be seriously questioned. Their effect on other plant populations is probably going to be slight: they will not be 'superweeds'. The difficulty for farmers is that the populations persisting in fields typically occur at around 100 m^{-2}, which (though a small fraction of the whole seedbank) is close to the stand-density of the crop, so even if 1 m^{-2} emerges in any future crop, it could cause impurity of 1%[12]. What is very uncertain is why its persistence is so variable between sites. The contributions of the genetics of the founder variety, the management and the local physical conditions have to be unravelled, and some progress will be possible by assessing persistence at the FSE sites.

Is coexistence between GM and non-GM feasible? While giving evidence to a committee of the Scottish Parliament[13], David Robinson of SCRI emphasised the argument that a type of crop or food can never be judged absolutely safe, since it is judged safe for practical purposes by showing the absence of harm under the conditions of the tests. People could go on for ever arguing that a foodstuff is unsafe. I do not believe that, for example, cooking-oil made from GMHT food-grade oilseed rape is harmful to eat. And I believe the same is largely true for other GM crops grown for food: at least, it is not their GM-ness that influences whether they are safe or not. To my mind, setting, and buying to, a threshold of impurity is mostly therefore for choice, not necessity, and the implications are economic, not environmental. If a farmer markets non-GM oilseed rape but their crop gets an impurity, then they lose money if they can't sell the crop.

We had direct experience of measuring and modelling impurities through traits that were introduced to both conventional and GMHT crops sown in the FSE. In the first instance, glyphosate-tolerance was introduced at low frequency in conventional oilseed rape. There was no issue of harm or benefit to environment or health. One of our crops on the research farm at SCRI contained the impurity, and we gained unique knowledge of its spatial distribution (mostly clumped around the GM mother plants) and its population dynamics. There was the usual clamour to disband the FSE after this impurity was announced and even more strident protestations after small amounts of seed with antibiotic resistance were discovered in GMHT seed lots by routine testing of GM trial seed. The impurities would have very minor ecological effects in these circumstances. The knowledge lost would have been considerable and detrimental to the debate. There were no logical reasons for disbanding the experiment.

Science meets reality In mid-2003, we were asked to advise on the real matter of sowing oilseed rape in fields used previously as FSE sites. We had been reporting to Defra on the decline rates of feral (volunteer) oilseed rape in fields[12]. An exhaustive review of existing data and thousands of simulations all indicated that sowing oilseed rape only two years after the GMHT crops could not guarantee meeting a threshold of around 1%, and certainly not the proposed threshold of 0.5% which the EU was considering for plants used in experiments such as the FSE. To meet the threshold of 0.5%, for instance, the feral weeds would have to emerge at less than 1 plant in 2 square metres of the rapeseed crop. This was unlikely at many sites after only two years, but we could not predict then which sites would meet the threshold and which not. Defra accepted our advice and asked the companies and the FSE farmers not to sow oilseed rape that year. I accept that we stuck our necks out on this one, and despite the ear-bashings from various interests, we had the confidence of having examined and re-worked all available knowledge. The question will be asked again.

Research over many years, and very much within the rough and tumble of the arable scene, leads us to conclude that (generally) outcrossing is too low between fields to prevent coexistence between GM and non-GM oilseed rape if the industry works to some reasonable threshold around 1%. In contrast, persistence of feral (volunteer) populations in fields is too great to allow rapid switching between GM and non-GM cropping in a field and achieve the same threshold with any certainty. It is not that impurities from volunteers cannot be reduced below 1% - they certainly can - but that a farmer should have doubt that it could be done within a reasonable time, say 5 years. This only applies to oilseed rape, and judgements have to be made by crop: maize, for instance, leaves no feral populations in GB. Our studies in coexistence will now be taken forward as a partner in a EU project, which aims to bring together similar work on outcrossing and persistence across Europe, and includes countries having a wide range of environments, crops and cropping patterns.

Activism and damage to sites The FSE team was often asked what effect damage through protest had on the results and their interpretation. The simplest answer is very little, in terms of data lost. Intentional damage reduced the base of knowledge, but nowhere near to the point where replication was compromised. Activism during the FSE was broad and varied in its intent and methods. We met groups and individuals who were highly committed to environmentalist causes, felt strongly about the creation of transgenic organisms or about the increased pressure on ecosystems, and tried to influence government policy rather than take direct action. There was also a "toffs with machetes" element to protest, a branch of activism that will fade, having no ideological or material base, much as mods and rockers no longer torment seaside towns in England. More widely, the national and multi-national activist groups did little to advance the causes of environmentalism. There was much posturing and position-taking among their representatives in GB but little of the environmental rationales of Fraser Darling[14] or Schumacher[15], of the political realism of Brandt[16] or the spiritual logic of Tenzin Gyatso[17]. Activism's establishment achieved little more than deflecting the public's attention from the important matter that, here for the first time, was an attempt to examine potential ecological impacts before a technology was introduced commercially. Activism also targeted many of the wrong people – family farms and young scientists included, many of whom are now dismissive of its tactics.

None of the FSE consortium suffered physical attacks (to my knowledge), or attacks on personal property, though some farmers did. The senior members of the consortium had their share of verbal abuse at public meetings, but even then I do not think the attacks were personal – in that you might be called a liar, mealy-mouthed, a cheat and so on, but it was mostly part of the activist game and not directed at you standing there. They would have said the same things whether you were there or not. Did the constant ridiculing through the media and internet affect morale in the FSE team? In some instances it did, but they were few. My younger colleagues at SCRI have a robust attitude to insult. At the few sites that did sustain repetitive damage, the plan was always to continue the sequence of measurements. It supported the farmers and gave least satisfaction to the damagers. By the end of the trials, many in the research group viewed routine, activist damaged much the same as they would bad weather – just another layer of environmental noise. As I have said, some of the farmers had a much harder time.

Peer review and reception of the first results The matter of peer review was also brought before the public and the media – that scientific papers are submitted to a journal, which has them scrutinised by experts in the subject, then rejects or accepts them. The Royal Society issued an explanation of the process of peer review[18], but while it stated that rejection did not necessarily mean that a work was inherently flawed, it was clear that collectively we had to achieve the standard for acceptance.

Peer review takes time. It was much faster for the media, working with activism, to fund some measurements and put out the results to greatest effect without any independent, critical review. This happened near the beginning of the experiments, when a national television news programme led on a story they had commissioned on pollen moving out from one of the FSE fields. The revelations were mostly existing knowledge, repackaged and sensationalised. If any of the scientists had so published without peer review, they should have been severely reprimanded, at least. We learned that even what appear to be authoritative news programmes take a line on issues!

How were the results of October 2003 received? In the UK, the GM Science Review[19] and the Advisory Committee on Releases to the Environment (ACRE)[20] endorsed the study and the findings. The response from EU member states has generally been constructive. Several countries have taken an interest in the results of both the food web and geneflow studies. Some states, notably Denmark, had considered all available information and put in place their own resolution to possible conflict[21]. We have advised commissions in other countries, including Sweden and France. Opinion from the UK's media on the conduct of the experiment and its findings was generally good: there was sufficient detail reported below the headlines to show that many journalists had taken the publication of results seriously. The headlines were mostly anti-GM, which distressed many biotechnologists. Some threw a few punches at the science of the FSE itself, but more reasoned reactions asked why the results had been so sensationally interpreted by the media[24]. The reasons for this are complex: biotechnology is still invisible and fearful to many people, and some of its proponents are dismissive when challenged. I support Joe Perry's reaction[22] to the 114 scientists who signed a letter to the Prime Minister deploring the headlines and asking for a rational response by government[23]. Where had such numbers been (we ask) while the FSE scientists were being thrashed in public, defending the right to do the field work on GMHT technology? If as scientists, we are not prepared to get out and talk to people, to convince them, then we should complain less when the public object.

More of substance to us was the criticism that the FSE had not measured everything or even not measured the right things[24]. It measured the things that were important for assessing GMHT cropping in GB at that time. Bulk offtake, as yield, was not measured. Rather, the mechanistic link between the crop and the food web was assessed through detailed measurements of the crop, its development, gross architecture, herbivores and their specialist consumers, all of which confirmed that the field management rather than the GM-ness of the crops affected the wider food web. The consortium nevertheless welcomed debate on what it had and had not measured: these are issues for the future.

Unintended outcomes The tactic by certain activist and media interests of attacking one or other senior members of the FSE group was not an effective means of deconstructing the research programme. Admittedly, it sometimes put great stress on the person, sometimes causing their wellbeing to suffer. The more general result of the pressures on the FSE was a strengthening of trust and dependence between colleagues and institutes. This in itself was good for the conduct of the science, since the work, and particularly the analysis of the results, was done in secrecy. There was no opportunity during the FSE to expose our thinking and early data in the semi-public arena of the scientific workshop. Not even the civil servants in Defra, nor the heads of the three research organisations knew the result. The scientists themselves, supported by members of the Steering Committee, simply had to get it right, and we were aided in this because circumstances had already forced us to rely on each other. We also demonstrated that a virtual project was feasible, where the science of the project, and the colleagues doing it, operated through web contact almost independently of the organisations. Of course, we relied on the infrastructure and expertise of the parent institutes, but once given the money and task, members of the groups got on with it, completed it and shared much more with each other than they would normally have done in a standard multi-partner project. More widely, the FSE and other studies in Europe have generated a research community which has a broad, holistic, agenda that combines many disciplines in basic and applied science. This community offers the potential to nurture young scientists and technicians, challenging their intellects and manipulative skills by major problems that are not narrow in discipline or technique.

The outcome and launch of the results relieved the pressure from journalists and public. There has since been less of a tendency for enquirers to assume we are going to lie or obfuscate. The following quote from the *New Scientist* magazine is welcome: "The green groups claimed the experiment was biased and the researchers were in the pocket of the biotech industry. It wasn't, and they weren't." However, such comment should not simply be accepted because it is commendatory. I suspect that fewer positive comments on the conduct and competence of the researchers would have been made if the GMHT cropping had shown strong positive effects on the arable food web, yet the conduct of the study would have been the same. Publicly funded science still has a task to convince people that it is not swayed by this or that global interest. Independence and security of funding are essential.

Some conclusions and next steps Many commentators see the FSE as having ended with the launch of the results for the spring-sown crops. This is not so. The results for autumn-sown (winter) oilseed rape, by far the main break crop in the UK, are a year later than the spring-sown crops, and will be analysed and completed in 2004. Carry-over effects on plant populations, particularly of the buried seed, and decline rates of the GM and conventional seed residues will continue to be measured. Analysis is in progress on outcrossing from GMHT crops to surrounding populations and fields during 2002 and 2003. The FSE group is working on the important matter of up-scaling the results to address 'what if' questions (e.g. what would be the effect on arable biodiversity as a whole if most break crops were GMHT?).

The FSE has shown that major ecological questions are tractable; that well designed and well executed experiments can sift the background noise to leave quite small effects of treatment. Given this, it is feasible to define general and widespread features of a sustainable arable system and determine which biotechnology best fits the habitat. Moreover, all new technology should be considered before it is implemented – certainly not just GM technology - and we should be able to move forward with less confrontation and position-taking than has been the case around the FSE. This far, the ecological effects of cropping with GM herbicide-tolerant varieties appear small, but by no means negligible, compared to many other factors of intensification and global change affecting the habitat's capacity to hold and recycle energy and nutrients. Was it worth it? Certainly, for the science, for the good colleagues, for the experience of the farms and farmers! Perhaps most rewarding for me is the knowledge that arable field systems are still potentially biologically rich and could be managed to balance yield and food web.

Acknowledgements

The FSE research group publicly thanked the civil servants, the companies, the Steering Committee, and the farmers for their essential contributions[25]. I personally thank my FSE colleagues at SCRI (particularly Dr Cathy Hawes), CEH and Rothamsted Research, and the Director of SCRI, Professor John Hillman, who from inception of the study in 1999 to the first publication in October 2003 gave undiminished trust and support (without pressing me to tell him the results in advance of the launch!).

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Mechanisms & Processes

G.C. Machray, J.W.S. Brown, K. Oparka & L. Torrance

An exciting year of research into the biology of the plant cell, and the pathogens that infect it, has seen landmark achievements, significant new scientific insights, and the establishment of key novel technologies across all three programmes (Gene Expression - GE, Cell to Cell Communication - CCC, and Plant-Pathogen Interactions - PPI) within the theme. Crucial to this success has been the development of productive collaborations between programmes in the theme, across SCRI, and worldwide.

For the first time in the UK, the genome of a plant pathogen, of major economic significance, has been completely sequenced and annotated (PPI, in collaboration with the Sanger Institute). The finished genome sequence of *Erwinia carotovora* subsp. atroseptica has already allowed SCRI scientists to uncover a number of novel putative pathogenicity genes, some of which have been confirmed *in planta*. It has led to the first microarray (PPI and GE) containing all the genes of this organism, allowing novel *in planta* gene expression studies. The sequence is also allowing bioinformatics approaches to uncover novel effector proteins involved in plant interactions, and offers many other possibilities for computational analyses, including a study of the evolution of this pathogen. The sequence will continue to act as a major resource for *Erwinia* biologists both at SCRI and in other groups around the world, with use facilitated through interactive web access.

The targeted sequencing of important loci in other plant pathogen genomes has revealed conservation of two avirulence loci between *Phytophthora infestans* and

Peronospora parasitica (PPI in collaboration with HRI, Wellesbourne). Sequencing around the *Atr1* avirulence locus in *Pe. parasitica* revealed open reading frames similar to ESTs in *P. infestans*. Probing a BAC library of *P. infestans* with these identified overlapping BAC clones and SNPs developed to the ends of these BAC clones have been used in association genetics studies to reveal linkage disequilibrium across a 100 kb region containing the *P. infestans Avr3* gene. This is the first demonstration of conservation of *Avr* loci in plant pathogens other than the *hrp* gene cluster in bacteria.

This work arose from the identification of candidate Avr genes from *Phytophthora infestans* (PPI in collaboration with the University of Ohio, USA). A combination of association genetics, using SNP analyses across a range of candidate *Avr* genes, and functional genomics, expressing the candidate genes in potato differentials using Potato virus X-based viral vector, revealed two candidate *Avr* genes, *Avr3* and *Avr2*. The former resides in a genomic region referred to above in syntenic studies, and the latter comprises a gene encoding a small cysteine rich protein that elicits the hypersensitive response in potato genotypes containing the *R2* gene.

These, and other current gene discovery programmes at SCRI, are producing large amounts of sequence data for which there is an urgent requirement to ascribe function. Following on from a successful collaboration (CCC with Large Scale Biology Corporation) that produced improved viral vectors for cell biological studies and the production of therapeutics in plants, additional vectors have been created to allow targeted gene silencing in plants. Gene silencing allows rapid and facile screens for gene function without the need to produce transgenic plants. A strategy using inverted repeat sequences and hairpin structures has been used to increase the efficiency of silencing, initially using vectors based on *Tobacco Mosaic Virus*. These vectors allow enhanced functional genomics screens that are being incorporated into the bioinformatics analyses that are occurring across the research programmes at SCRI.

Further novel viral vectors that infect diverse species such as *Arabidopsis*, potato and barley have been generated (CCC). This work, funded by the SEERAD 'outer core' programme, is aimed at exploiting viral vectors as functional genomics tools for high-throughput analysis of novel gene sequences arising from SCRI-based genomics programmes on potato and barley. New vectors based on *Barley Stripe Mosaic Virus* and other plant viruses that infect monocotyledonous hosts, together with *Potato Virus X* (PVX), *Tobacco Rattle Virus* and *Potato Leaf Roll Virus* have been created so that gene function can be determined through gene silencing or over-expression.

Using the PVX vector the first gene silencing in potato tubers (PPI, CCC and QHN) has been demonstrated. The endogenous *pds* gene was silenced, leading to a photo-bleaching phenotype in tetraploid cultivars (Desiree, Bintje and Stirling) of *Solanum tuberosum* and in the diploid wild potato species *S. bulbocastanum*. Up to 80 % silencing at the transcriptional level was seen and HPLC revealed accumulation of phytoene (the substrate of phytoene desaturase). Silencing in tubers was maintained through several generations of micro-tuberisation.

A system that allows RNAi to be used as a tool to knock out expression of putative plant parasitic nematode pathogenicity genes has also been developed (PPI). Use of this technique to knock out expression of genes encoding secreted cellulases significantly impaired the ability of the nematodes to invade host roots. Similarly, knock out of a gene encoding a secreted protein of the amphids (the main sense organs in nematodes) almost completely abolished the ability of the nematodes to locate and invade host roots. This system will allow the function of genes potentially involved in nematode feeding site induction to be tested. It will also allow us to assess the effects of disrupting various nematode genes and thus identify suitable targets for novel control methods. A further technology with potential applications in functional genomics and clean GM technology is based around homologous recombination between DNA sequences (GE). Using artificial target sequences presented in the genome in a test system involving the preparation of tobacco microspores and *in vitro* maturation to pollen grains, a rate of homologous recombination around 2% is indicated, which is probably the most efficient in plants to date. Currently the frequency of targeting of endogenous genes, the mechanism of homologous recombination involved in this system, and its transfer to crop plants are being investigated.

Novel proteomics initiatives have also generated significant results. An analysis of the nucleolar proteome of *Arabidopsis* is underway with the identification of over 200 proteins from isolated nucleoli (GE in collaboration with JIC and the University of Dundee). From bioinformatics analysis of the 200 proteins, complemented by localisation within the cell of a third of the proteins generated from GFP-fusions of full-length cDNAs , >90% of the proteins have nucleolar or nucleolus associated labelling. Currently, a direct comparison of the plant and human nucleolar proteome is being carried out and has identified proteins of unknown function conserved in both organisms, and plant-specific proteins. A novel viral-vector screen has been used to ascribe subcellular localisations to proteins derived from hundreds of random GFP-fused sequences from cDNA libraries leading to the first isolation of plasmodesmal protein genes (CCC). For both research areas the provision of a web-based database for use by the wider research community has been undertaken.

Two areas of research with plant virus proteins, involved in silencing suppression, have demonstrated the link between basal RNA metabolism and RNA silencing (GE, in collaboration with the Sainsbury lab). The proteins, from two completely different viruses, interact with an RNA export factor and a nucleolar protein required for processing and modification of rRNAs. Further studies have continued to characterise the function of the viral movement proteins (MPs) and how they interact with plasmodesmata (CCC). Using novel FRAP (Fluorescence Recovery After Photo-bleaching) methods, and a number of cell biological and chemical inhibitor-based studies, it has been conclusively shown that the MP of *Tobacco Mosaic Virus* does not move on microtubules (contrary to current dogma) and that the endomembrane system is likely to play an important role in the trafficking of viral movement proteins, and endogenous proteins from one cell to another. Similar approaches will be taken in the future to functionally characterise the plasmodesmal proteins that are discovered from the GFP-library screens above. In addition, work on subcellular localisation of *Potato mop-top virus* triple gene block proteins (PPI/CCC) has shown that proteins p2 and p3 utilise the endoplasmic reticulum (ER) and ER-derived compartments for intracellular movement. A motif in p3 that targets the protein to ER membranes may function also as a MP target signal.

The fusion between molecular biology, cell biology and bioinformatics of plants and their pathogens, as illustrated above, provides a powerful tool for the analysis of gene function as plant science matures into a postgenomic era. High impact factor publications and notable successes in the acquisition of external funding for fundamental studies and, for example through DTI-Link and Scottish Enterprise funding, for their application, will ensure the translation of these research discoveries to practical benefit.

Proteomic analysis of the *Arabidopsis* nucleolus

J.W.S. Brown, G.P. Clark and D. Lewandowska

Plant and cell growth and development depend on the regulation of expression of thousands of genes. Regulation occurs at a number of different levels, such as transcription, RNA processing and translation. The cell must produce all of the machinery required to switch genes on and off, to process and transport RNAs, to translate mRNAs into proteins and to produce protein or protein-RNA complexes. Transcription and processing occur in the nucleus and the wide range of different activities which underpin gene expression involve many sub-compartments or bodies within the nucleus, and dynamic interactions of different components and machineries among these sub-nuclear bodies. The most prominent nuclear sub-compartment is the nucleolus. The nucleolus is traditionally recognised as the site of ribosome production involving ribosomal DNA transcription, ribosomal RNA processing and ribosomal subunit assembly. However, over the last five years it has become apparent that the nucleolus is involved in a much wider range of activities and processes. For example, it is involved in aspects of processing or export of some mRNAs and tRNAs, the processing and assembly of RNA-protein particles (RNPs) such as telomerase RNP and the signal recognition particle (SRP), and potentially in RNA turnover and nuclear translation.

In plants, the only nuclear bodies identified so far are the nucleolus, and Cajal bodies, which function in the maturation of small nuclear and nucleolar RNPs. To understand the complex events underpinning gene expression, we have carried out a proteomic analysis of nucleoli purified from protoplasts of *Arabidopsis.* This work has been carried out in collaboration with the research groups of Prof. Peter Shaw, John Innes Institute, Norwich, and Prof. Angus Lamond, University of Dundee (responsible for characterisation of the nucleolar proteome of humans). The analysis of the *Arabidopsis* nucleolar proteome allows a comparative proteomic analysis of these two widely separated higher eukaryotes to identify common and species-specific nucleolar components. We have so far identified around 200 different proteins, including ribosomal proteins, known nucleolar and RNA-binding proteins, putative DNA/chromatin binding proteins, histone acetylases/deacetylases, DEAD box helicases, splicing and translation factors, putative RNA transport factors and snoRNP core proteins. In addition, we have identified proteins which are specific to the plant nucleolus, with no homologies to human proteins, and proteins of unknown function which occur in both the plant and human nucleolar proteome, suggesting a conserved function. We are currently fusing available full-length cDNAs for the identified proteins to the green fluorescent protein (GFP) to examine the localisation of the proteins in *Arabidopsis* cells (Figure 1). To date, the high percentage of GFP fusions showing nucleolar labelling highlights the quality of the plant nucleolar preparation. Detailed analysis of their sub-nucleolar location will provide clues about potential functions of the proteins and the different processes in which they are involved.

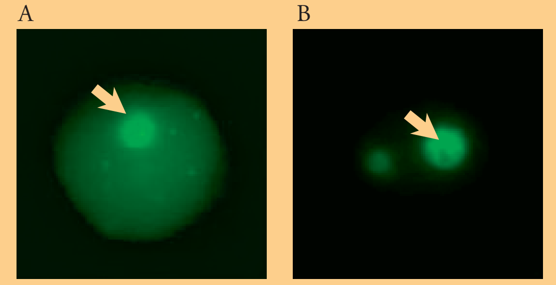

Figure 1 Nucleolar localisation of proteins of unknown function which are plant-specific (A) or found in both plant and human nucleolar proteomes (B). Arrows indicate nucleoli.

Involvement of nucleolus in plant virus infection

M. Taliansky, S.H. Kim, E.V Ryabov, B. Reavy & D. J. Robinson

The past few years have brought remarkable progress in our understanding of the genome organization and expression of umbraviruses (Taliansky and Robinson, 2003). At the same time, the recent findings raised some new and fascinating questions related to basic molecular processes in plants. Involvement of the nucleolus in umbravirus infection is among them.

The nucleolus is a prominent subnuclear domain and is classically regarded as the site of transcription of rRNA, processing of the pre-rRNAs and biogenesis of pre-ribosomal particles. However, in addition to these 'traditional' nucleolar activities, the nucleolus also participates in many other aspects of cell function. Thus, because of sequestration and maturation of several factors and regulatory complexes, the nucleolus is involved in the regulation of signal recognition particle biogenesis, small nuclear RNA processing, mRNA nuclear export, telomerase activity, the cell cycle, cell growth and aging.

Umbravirus-encoded ORF3 protein is a multifunctional RNA-binding protein involved in phloem-associated long-distance movement of viral RNA, and its protection from RNase attack (Ryabov *et al.,* 1999; 2001 see also *SCRI Ann. Rep. 1999/2000, 144-146*). Localization studies showed that the ORF3 protein encoded by *Groundnut rosette virus* (GRV, an umbravirus) accumulated in cytoplasmic granules. These granules consisted of filamentous ribonucleoprotein (RNP) particles, contained viral RNA and the ORF3 protein. It is suggested that these RNP particles serve to protect viral RNA, and may be the form in which it moves through the phloem. (Taliansky *et al.*, 2003). Formation of the cytoplasmic RNP complexes may also be involved in the protection of viral RNA from the plant's defensive RNA silencing response. Consistent with this suggestion, heterologous expression of the ORF3 protein in cultured *Drosophila* cells led to formation of similar particles in the cytoplasm of the cells. The RNA content of these particles produced in *Drosophila* cells is not presently known but expression of the ORF3 protein led to suppression of RNA interference in the *Drosophila* cells.

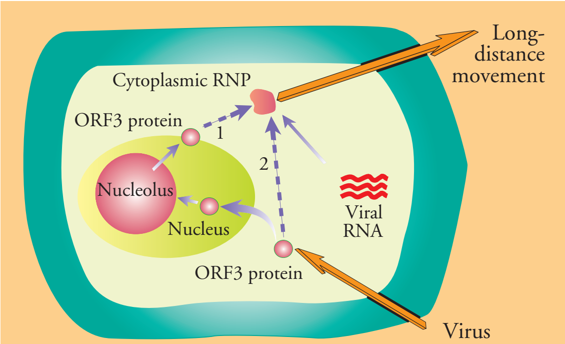

Figure 1 Schematic diagram of the pathway taken by umbraviral ORF3 protein in an infected cell. It is unclear whether the protein reaches the cytoplasmic RNP complexes from the nucleus/nucleolus (1), or directly through the cytoplasm (2).

The studies of localization of the ORF3 protein also provided another quite unexpected finding; in addition to the cytoplasmic granules, the ORF3 protein was also found in nuclei, preferentially targeting nucleoli. Comparison of amino acid sequences of the umbraviral ORF3 proteins revealed two highly conserved domains one of which included an R-rich sequence and another one contained invariant L residues. Alanine scanning mutagenesis showed that both the R-rich and L-rich domains were involved in the localization of the ORF3 protein to the nucleolus. In addition, the L-rich domain also functioned as a nuclear export signal (NES), suggesting that the ORF3 protein is a nuclear/nucleolar shuttle protein. Functional analysis of the mutants revealed the correlation between the ORF3 protein nucleolar localization and its ability to transport viral RNA long distances *via* the phloem. The likely pathways taken by ORF3 protein in infected plant cell is illustrated in Fig. 1. This suggests that the nucleolar functions could be involved in the process of long-distance RNA movement and possibly protection of RNA from RNA silencing.

How and why does the umbravirus protein modify nucleolar activities? Does it interact with RNA components of the nucleolus, such as rRNAs or small nucleolar RNAs to modify RNA metabolism or does it bind to one or more nucleolar proteins, inhibiting their enzymatic or other activities? Does the ORF3 protein have an effect on nucleolar sequestration of the cell growth and cell cycle regulators? Future research will address these questions and attempt to open up the "nucleolar black box" in our understanding of the functional links between nucleolar functions and long-distance virus (and more generally, macromolecular) transport in plants.

High-throughput gene expression analysis at SCRI

P. Hedley & J. Morris

Exploitation of genomics resources Major investments have been made in the last few years at SCRI to establish extensive catalogues of genes, as expressed sequence tags in crop plants and through whole genome sequencing in plant microbial pathogens. In order for these resources to be fully exploited in crop improvement and research programmes, high-throughput monitoring of gene expression is required. Determination of coordinated changes in gene expression over time, throughout development, or in response to manipulation, stress or pathogens, will allow novel insights into how they respond to environmental challenges.

Utilisation of current technology Parallel gene expression technologies currently being developed and utilised at SCRI include microarrays and serial analysis of gene expression (SAGE). These tools enable the simultaneous analysis of the activities of many thousands of genes, providing targets for detailed downstream studies. There are two main microarray platforms being optimised at SCRI. Spotted arrays, which consist of DNA probes (as PCR products or oligonucleotides) deposited onto modified glass slides, and Affymetrix GeneChip technology, where each gene is represented by a set of short oligonucleotide probes. RNA is isolated from target tissues and labelled as cDNA, prior to hybridisation against the arrayed gene probes. SCRI has acquired a Genetix QArray Mini spotting robot for microarray fabrication, along with an Applied Precision ArrayWoRx scanner for data acquisition. In addition, for GeneChip studies, a hybridisation and analysis node has recently been purchased. Following data extraction, exploitation of data is subsequently performed using GeneSpring (Silicon Genetics) software, which allows identification of differentially expressed genes, comparison of expression profiles, clustering analysis and links to metabolic pathways. The Computational Biology programme and BioSS are providing support for analysis and data storage.

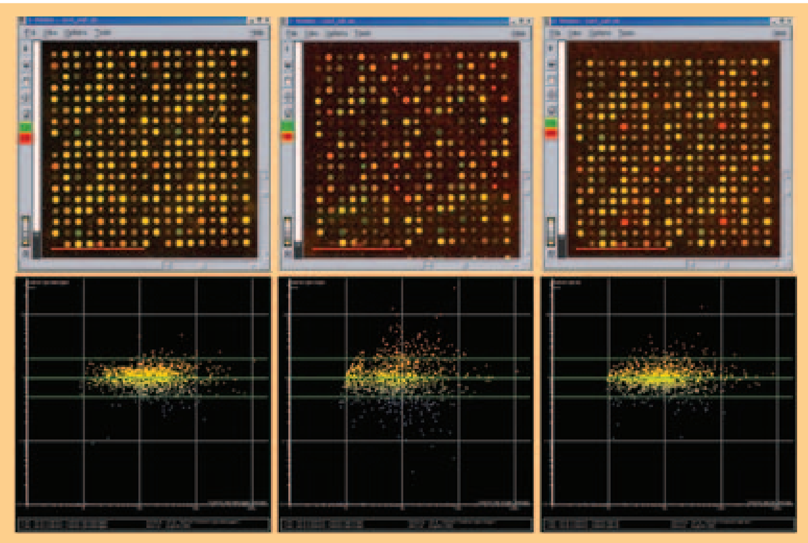

Figure 1 Differential gene expression in stressed barley root tissue.

Collaborative projects Affymetrix GeneChips are now available for barley from a collaborative effort between SCRI and a USDA-funded initiative. These arrays contain approximately 23,000 probe sets representing high-quality barley gene sequences. It is envisaged that several collaborative projects will utilise these arrays, including dissection of malting characters and grain development, and plant response to abiotic stress. GeneChips representing 22,000 *Arabidopsis* genes will also be utilised wherever appropriate. The genome sequence of the potato pathogen *Erwinia carotovora* ssp. *atroseptica* has recently been completed at SCRI and each gene (approx. 5000) will be represented on Agilent oligonucleotide arrays, along with a set of potato genes (approx. 1000) implicated in defence responses. These arrays will be used to identify novel pathogenicity genes *in vitro* and *in planta*, and to study host-pathogen interactions. In addition, projects are also underway to investigate regulation of alternative splicing in *Arabidopsis*, global control of carotenogenesis in potato, dormancy in raspberry, the role of transcription factors in biotic responses of potato and potato-nematode interactions. Linear amplification technologies are also being developed to allow expression analysis from small numbers of target cells.

Developing 'silencing-based' GM resistance to viruses

H. Barker & K.D. McGeachy

Crops that are grown from vegetatively produced planting material (such as potato) can suffer with virus diseases that accumulate and increase each planting season. Because aphids transmit many of the important viruses that infect potato, substantial amounts of insecticides are applied to seed and ware potato crops to kill aphids, but frequently are only partially effective in controlling virus spread. Growing virus resistant cultivars could provide an economic and environmentally acceptable control method but incorporation of resistance genes by conventional breeding is slow and expensive and therefore few cultivars contain resistance genes to more than one or two viruses. Use of genetic manipulation to introduce transgenes, based on expression of plant virus sequences, that induce resistance is one means by which these problems can be overcome. More specifically the development of transgenes based on expressing short non-translatable virus RNA sequences simultaneously in sense and antisense orientation has been found to be a promising way to overcome some of the problems associated with the first generation of virus resistance transgenes. Expression of sense and antisense RNA from the transgene induces a strong form of virus resistance through an RNA-mediated defence mechanism that is based on post transcriptional gene-silencing. We are developing this technology in order to obtain resistance to a wide range of potato viruses and have already developed resistance to one of the most important potato viruses, *Potato virus Y* in tobacco, an excellent model species for virus resistance work.

Figure 1 A transgenic plant was grafted with a PVY^{O} infected shoot from a wild-type plant (left) and was allowed to remain on the plant as it grew. Three weeks after inoculation the shoot from the transgenic plant (right) was found to be virus-free and remained non-infected as the plant grew. Typical mottling symptoms of PVY^{O} can be readily seen in the wild-type shoot (left), but not in the resistant transgenic shoot (right).

A sequence encoding approx 800 nucleotides from the genome of an O strain of PVY (PVY^{O}) was cloned and incorporated into a plant transformation vector in sense and antisense orientations and used to produce transgenic tobacco lines. The sense and antisense transgenes were introduced into the same progeny plants by cross-fertilisation. Of 30 F_1 lines containing the both transgenes, 9 lines were resistant to mechanical inoculation with the homologous PVY^{O} isolate. Some resistant lines were also tested using the most severe form of challenge inoculation that can be used, namely graft inoculation (Figure 1). Despite the severity of the challenge inoculation, plants remained non-infected. Resistance was assessed in a number of ways; plants developed no symptoms, virus could not be detected by enzyme-linked immunosorbent assay, and attempts to recover infectious virus by inoculation of sap from resistant plants were unsuccessful.

This deliberate targeting of gene silencing-based virus resistance has been successful and has provided information on how to extend the method to other viruses. More advanced transgenes that are designed to induce silencing resistance are being constructed and tested at the moment. It is hoped that the technique will eventually produce a universal means by which resistance can be induced against a wide range of viruses and can be applied to many crops.

Studying plasmodesmal targeting of TMV-MP using FRAP

K.M. Wright, N.T. Wood[1], K.MacKenzie[2] & K.J. Oparka

Tobacco mosaic virus (TMV) is frequently studied as a model system to identify the mechanisms involved in plant viral infections. The structure and functions of all its genes have been identified and of particular interest is the 30-kDa protein required for cell-to-cell movement. This movement protein (MP) is involved in the transport of viral RNA to and through plasmodesmata (PD). TMV-MP accumulates within PDs and increases the size-exclusion limit of the PDs to allow trafficking of viral RNA to the next cell in the form of a MP-complex.

In recent years it has been possible to produce TMV derivatives that express fully functional MP fused to green fluorescent protein (GFP) thus enabling visualisation of the MP. At the leading edge of an infection, and throughout the infection site, MP is located within PDs. Near the edge of an infection, MP is associated with vertices of the cortical endoplasmic reticulum (ER) whilst further in the MP can be seen aligning with the microtubules (MT). Some researchers have speculated that MT are involved in the targeting of TMV-MP to PDs. However, at SCRI we have shown that disruption of MT with pharmacological agents has no effect on lesion growth and we suggest that MT are instead involved in the degradation of MP later in the infection process.

We are therefore investigating the targeting of MP to PDs using a technique called fluorescence recovery after photobleaching (FRAP). Tobacco leaves are infected with TMV-MP-GFP virus and the edge of the infection site located using a confocal laser scanning microscope. Using the laser it is possible to bleach the fluorescent GFP attached to MP within a PD. Images are recorded and then measured as the fluorescence increases due to the movement of new MP-GFP into the PD. Over the course of 40 minutes, under control conditions, the fluorescence recovers to approximately 40% of the pre-bleached value (see figure 1). We have tested whether this fluorescence recovery is influenced by a range of inhibitors that target the action of different cell components.

Provisional results indicate that movement of MP to the PDs is energy dependent since it is severely reduced in the presence of azide, a metabolic inhibitor (see figure 1). BFA, which disrupts the ER network, BDM, an inhibitor of myosin motors, and both cytochalasin and latrunculin, which affect actin activity, also decrease fluorescence recovery. However, colchicine and oryzalin, which inhibit MT action, and cycloheximide, an inhibitor of protein synthesis do not appear to have any effect on the fluoresence recovery. This therefore supports the view that MT are not involved in the movement of MP to PDs. We therefore propose that a mechanism involving the ER and the actin network is reponsible for trafficking MP to the PDs.

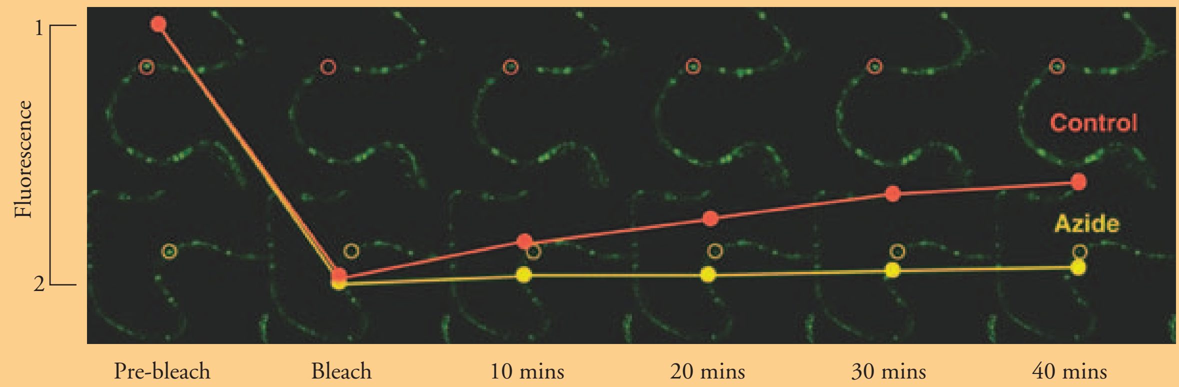

Figure 1 Images in the background illustrate the FRAP treatment of a PD under control conditions (see green PD within upper red circles) compared with the low level of recovery when treated with azide (green PD within lower yellow circles). The fluorescence intensity of these PDs was measured and is presented in the graph as a proportion of the pre-bleached value against time.

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Viral Induced Gene Silencing in Crop Species

K. Hrubikova, E. Gilroy[1], O. Faivre-Rampant, G. Loake[1], P. Birch, M. Taylor & C. Lacomme

Virus induced gene silencing (VIGS) is being used increasingly for reverse genetics because it offers a means for rapid gene knockdown by avoiding stable transformation (Baulcombe 1999). VIGS is an RNA-mediated defense mechanism that directly targets the integrity of the invading viral genome in a sequence-specific manner, and subsequently lowers the titer of the invading virus through an endogenous RNAse-inducible mechanism, which leads to viral RNA degradation (Baulcombe, 1999). By introducing plant cDNA fragments into the viral genome, it is possible to redirect this mechanism to corresponding endogenous host mRNAs, thus providing a means to down-regulate host gene expression.

A PVX vector triggers VIGS of endogenous *pds* in foliar tissues in *Solanum* species. In order to develop VIGS for functional genomic in *Solanum* species, the capacity of a previously described binary-based PVX vector (Jones *et al.*, 1999) was tested for its capacity to infect both wild diploid and cultivated tetraploid *Solanum* species. Cultivars were selected on the basis of their ability to be stably transformed and propagated *in vitro* (*Solanum tuberosum* L. cv Desiree), differential interactions to *Phytophthora infestans* between susceptible and resistant cultivars (*S. tuberosum* L. cvs Bintje and Stirling, respectively; Birch *et al.*, 1999), or their potential as a source of novel resistance genes to *P. infestans* (*S. bulbocastanum*, Song *et al.*, 2003). The efficacy of the PVX vector in silencing was assessed through its ability to silence an endogenous phytoene desaturase (*pds*) gene in these *Solanum* species. Down-regulation of *pds* triggers a characteristic photobleached phenotype (Kumagai *et al.*, 1995). As RNA silencing is homology-dependent, a potato *pds* cDNA fragment was isolated and cloned in antisense orientation into the PVX vector (PVX.PDS$_{AS}$ construct). By 3 weeks post inoculation photobleaching was observed in all infected *Solanum* representing either diploid (*S. bulbocastanum*) or tetraploid (*S. tuberosum* L. cultivars, fig 1). The silenced phenotype correlated with a four- to five-fold decrease in normalized *pds* mRNA levels in all silenced *Solanum* plants. Further HPLC analysis of phytoene levels (the substrate of PDS) showed a five-fold increase increased in the silenced plants (fig.2, left).

Systemic VIGS of pds in potato tubers and *in vitro* generated microtubers. Although VIGS proved effective in potato leaves, much research in potato is directed at improving storage organ quality and resistance to pathogens. Therefore it was important to determine whether gene silencing was observed in tubers. Phytoene levels in tubers harvested from glasshouse grown potatoes challenged with PVX.PDS$_{AS}$ increased by up to five-fold in comparison to control PVX.GFP infected plants (fig. 2, center). This indicates that systemic *pds* silencing does not only extend to foliar tissues but is transmitted through the whole vascular system to tubers. Due to the variability in tuberization time, tuber size and the glasshouse space required for higher-throughput gene function analysis, *in vitro* grown potato could provide an interesting alternative for reverse genetics approaches to study tuber-associated functions, as *in vitro* microtuberization is synchronized and controlled. We therefore evaluated the potential of a VIGS-based approach for *in vitro* propagated potato. *In vitro* grown plants were

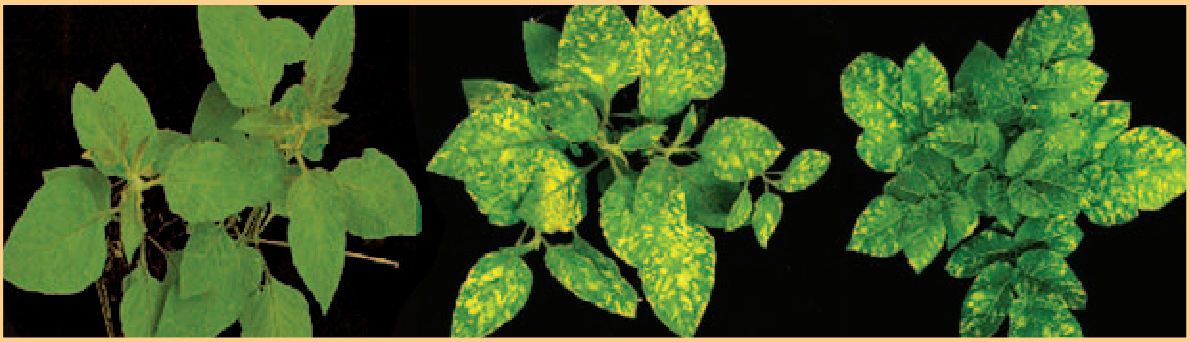

Figure 1 Silencing of the endogenous *pds* gene in *Solanum* species leads to photobleaching of the leaves (from left to right *Solanum bulbocastanum* non-silenced, *S. bulbocastanum* and *S. tuberosum* cv Bintje *pds* VIGSed).

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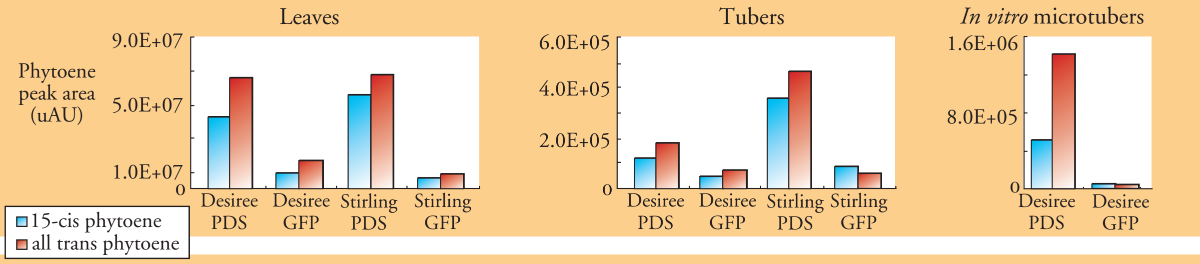

Figure 2 Increased phytoene levels in *pds* VIGSed potato in leaves, tubers and in vitro generated microtubers.

stab-inoculated (Takken *et al.*, 2000) with PVX.PDS$_{AS}$, and photobleaching was observed by 3 weeks post-infection. Micropropagation of VIGSed plants regenerated plants displaying a comparable photobleaching phenotype (sustained up to the fifth micropropagation event). In parallel, *in vitro* microtubers deriving from *in vitro* VIGSed plants were collected to monitor the extent of accumulation of phytoene. In these silenced microtubers, phytoene accumulation increased by 20-fold over than control microtubers infected with PVX.GFP (fig. 2, right), indicating that silencing was triggered efficiently *in vitro*.

Conclusions. We report the first example of an efficient VIGS-mediated manipulation of gene expression in both diploid and tetraploid potato (Faivre-Rampant *et al.*, in press). The microtuberization system, in conjunction with VIGS, has a number of potential benefits compared with analysis of tubers produced conventionally by glasshouse-grown plants. This should enable easier identification of altered tuber phenotype and opens the way for high throughput analysis of gene function enabling screening of genes involved in important traits such as tuber development, metabolism, and pathogen resistance.

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Knockout of PCN genes using RNAi

Q. Chen & J.T. Jones

Many genes have been identified from the potato cyst nematode (PCN) *Globodera spp* that may play a role in parasitism of plants. This information can be used to identify important nematode proteins that might be useful targets for novel control methods. However, before this can be done it is necessary to understand the function of the proteins encoded by the genes. Predicting function of some genes is straightforward. For example, one group of nematode proteins is similar to plant cell wall degrading enzymes. However, many proteins have no similarity to any other genes in the databases. In order to analyse the function of these genes systems for studying nematode gene function *in vivo* are needed. One technique that offers this possibility is RNA inhibition (RNAi). The basis of this technique is that exposure of an organism to double stranded RNA (dsRNA) generated from a gene of interest causes down regulation of the gene and, as a result, levels of the protein encoded by the gene drop dramatically. A recent paper described a method for using RNAi with PCN J2s. We have further developed this technique to allow it to be used with secreted proteins.

Nematodes locate their hosts by chemoreception using two sense organs – the amphids – located at the anterior tip of the nematode. In our previous work we identified a secreted protein expressed in the amphids (Figure a). We have now used RNAi to knock out expression of this gene. The rationale for this was that ablating a sense organ protein should inhibit sensory perception, giving rise to a phenotype that can be scored easily – an inability to locate host roots. Nematodes were soaked in dsRNA generated from the amphid gene (ams-1) (or in soaking solution without dsRNA for the controls) and then split into two batches. One batch was used for invasion studies while the other batch was used in RT-PCR experiments in order to demonstrate that we had successfully knocked out expression of the ams-1 gene without affecting expression of another control gene (actin). These experiments showed that the actin gene could be successfully amplified from both control and dsRNA soaked nematodes whereas the ams-1 gene was far more readily amplified from the control nematodes than from the soaked nematodes, indicating a reduced level of expression of the ams-1 gene in the dsRNA soaked nematodes (Figure b). These results were mirrored in invasion studies in which the dsRNA treated nematodes showed an almost complete inability to infect host roots (Figure c). These experiments have now been repeated using another gene, a secreted cellulase that is thought to be important in invasion and migration. Nematodes treated with this dsRNA also showed a statistically significant reduction in their ability to infect roots (Figure d). Those nematodes that managed to invade roots and establish feeding sites were examined in more detail. The developmental fate of these nematodes was no different to that of the controls suggesting that for this gene the RNAi procedure generated silencing in some nematodes but not others.

This work shows that RNAi can be used to investigate the function of genes implicated in the parasitic process of PCN. We are currently investigating the function of other putative parasitism genes using this technique.

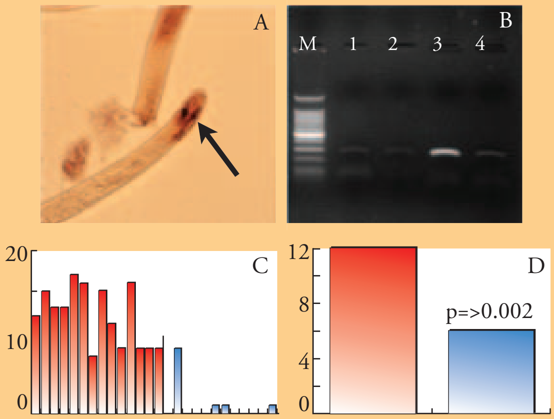

Figure 1 A: *in situ* hybridisation reaction showing expression of the *ams-1* gene in the amphids (arrows) of PCN. **B:** RT-PCR reaction showing PCR products obtained using actin primers from control (lane 1) and ams dsRNA treated (lane 2) samples and PCR products obtained using ams-1 primers from control (lane 3) and ams dsRNA treated (lane 4) samples. The data show that the ams-1 mRNA is less abundant in the dsRNA treated samples but that expression of other genes is unaffected. M = marker. **C:** Infection of potato plants by control (red) or ams dsRNA treated (blue) nematodes. Each bar represents a replicate experiment. Nematodes treated with ams dsRNA are far less able to locate host roots. **D:** Average infection of potato plants by control (red) or cellulase dsRNA treated nematodes. Nematodes treated with cellulase dsRNA are significantly (p= 0.002) less able to infect potato plants.

New discoveries with *Erwinia* genomics

I.K. Toth, L. Pritchard, M.C. Holeva, L.J. Hyman, K.S. Bell, S.C. Whisson, A.O. Avrova & P.R.J. Birch

Erwinia carotovora subsp. *atroseptica* (*Eca*) is an economically important pathogen of potato, causing blackleg of plants in the field and soft rot of tubers post-harvest. Its pathogenicity is primarily dependant on the tightly regulated production of large amounts of extracellular enzymes that degrade plant cell walls, with other factors such as iron acquisition and mechanisms to defend against plant attack also playing a role. In recent years, however, it has become clear that soft rot pathogenesis is more complex than previously thought and the relationship between *Eca* and potato / non-host plants is still far from understood. As a new approach to gene discovery in *Eca,* the complete genome sequence and annotation of *Eca* was determined in collaboration with the Sanger Institute, Cambridge, UK and SCRI through SEERAD funding. The genome is ca 5 Mb with 4, 491 coding sequences.

Analysis of the genome, and comparison with 60 other bacterial genomes using bioinformatics has revealed a wealth of new information, including putative pathogenicity factors previously unknown in this organism. For example, we have discovered i) a number of putative toxin genes, including those possibly involved in the formation of the polyketide-based coronafacic acid (part of the plant toxin coronatine produced by *Pseudomonas syringae* during infection); ii) a cluster of genes similar to a type IV secretion system that, in the plant pathogen *Agrobacterium tumefaciens,* plays a major role in the disease process.

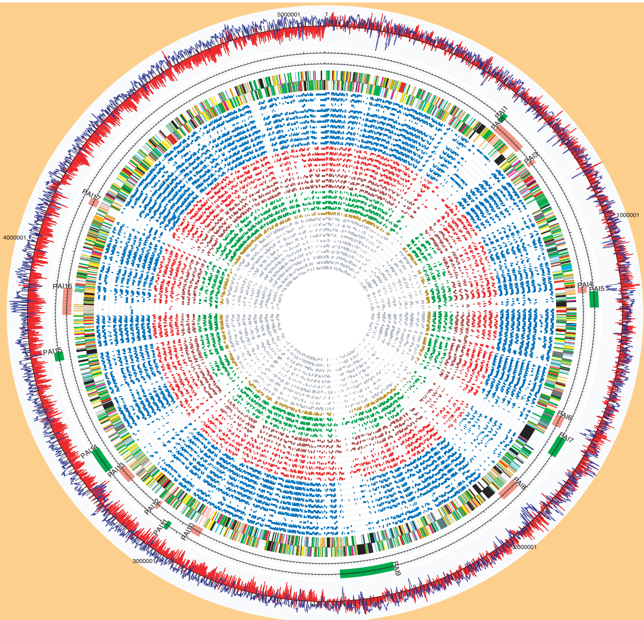

Figure 1 Comparison of the *Eca* genome sequence with other bacterial genomes: Inner to outer tracks: the locations of reciprocal best hits found by reciprocal FASTA of *Eca* CDSs against those from 32 bacterial genomes: Gram+ (grey); *Shewanella oneidensis* (ochre); non-enteric animal pathogens (green); plant-associated bacteria (brown); non-enteric plant pathogens (red); enterobacteria (blue). The locations of CDSs on the *Eca* genome, coloured by functional class. Two tracks indicating islands listed in Table 1: islands with evidence of recent acquisition (red bars), possible islands based on reciprocal FASTA analysis (green bars). A plot of G+C skew (red) and %GC content (blue).

We have also found that the number of pathogenicity genes acquired from more distantly-related bacteria, possibly *via* horizontal gene transfer, was greater than expected. Many of these distantly-related bacteria are plant pathogenic or plant associated, suggesting that *Eca* may have developed its plant pathogenic lifestyle through gain of important genes, following exchange of DNA with bacteria relevant to a plant associated lifestyle.

In collaboration with the *Phytophthora infestans* group at SCRI, we have developed a 'transposon mutation grid', allowing pooled libraries of transposon mutants to be searched rapidly for mutations in any given gene in the genome. We also have potato plants, obtained as miniplants from a commercial source, available for disease testing throughout the year. Using this dual approach over the last 6 months, we have isolated over 20 *Eca* mutants and determined the role of some important novel genes in pathogenicity, including those associated with both the coronafacic acid and type IV secretion system.

Finally, a number of other functional genomics programmes are being developed i) at SCRI, including microarrays containing the complete set of *Eca* coding sequences, to study the genome at the gene expression level both *in vitro* and *in planta*; ii) in collaboration with other institutions, such as Cambridge University and Moredun Research Institute, including proteomics to study the genome at the protein level.

Targeting late blight with gene discovery

S.C. Whisson, A.O. Avrova, M.R. Armstrong, J.T. Jones, E. Venter,and P.R.J. Birch

Introduction Potato is the fourth most valuable crop and the highest ranked non-cereal crop. The global area sown to potatoes is increasing at a rate of 4.5 % p.a. and the geographical range in which it is grown is expanding. However, potato has a major disease problem in *Phytophthora infestans*, the cause of late blight. Late blight occurs almost everywhere that potato is grown. *P. infestans* caused the nineteenth century Irish potato famine when Ireland lost over one million people to either starvation or emigration. These impacts can still occur where potato is cultivated as a staple food crop by smallholder or subsistence farmers. On a larger production scale, direct disease losses and costs of disease control are estimated to cost over £50 million p.a. in Britain alone (estimated at £3 bn p.a. globally). Control and management of late blight relies heavily on the regular application of costly control chemicals, but *P. infestans* insensitivity to some chemicals has been recorded. Major genes (*R* genes) for late blight resistance in potato have been used in the past, with limited success, as *P. infestans* has rapidly overcome most major *R* genes.

P. infestans is frequently considered to be a 'fungus' due to its mycelial growth habit, but belongs to a class of organisms known as the oomycetes, more closely related to the wider grouping of the Stramenopiles. This taxonomic affinity gives it many unusual characteristics, compared with the true fungi. The greater significance of this is that many genetic, molecular biological, and plant pathogenesis characteristics that have been determined for the true fungi do not apply, or need to be determined for *P. infestans*.

Recent years have witnessed a burst of activity within the oomycete research community. For example, resources such as expressed sequence tag (EST) databases, limited genome sequencing, large insert DNA libraries, genetic maps, and evolving techniques for functional analysis of genes are now available for *P. infestans*. The high-throughput strategy that characterizes genomic research now allows us to target the genes involved in the molecular interaction of *P. infestans* with potato.

Gene discovery Key targets of SCRI *P. infestans* gene discovery are genes required for the establishment of a successful infection of potato; these genes are likely to be expressed very early in the interaction. The infection strategy of *P. infestans* involves differentiation into as many as five different cell types in the following order (Figure 1): sporangium, zoospore, germinating cyst, appressorium, infection vesicle (*in planta*). It is likely that genes essential for successful infection will be expressed in those structures formed just prior to the invasion of host tissues. Techniques for targeted gene discovery such as amplified fragment length polymorphism mRNA fingerprinting (cDNA-AFLP; Figure 1) and suppression subtractive hybridisation (SSH) have been used to identify genes up-regulated

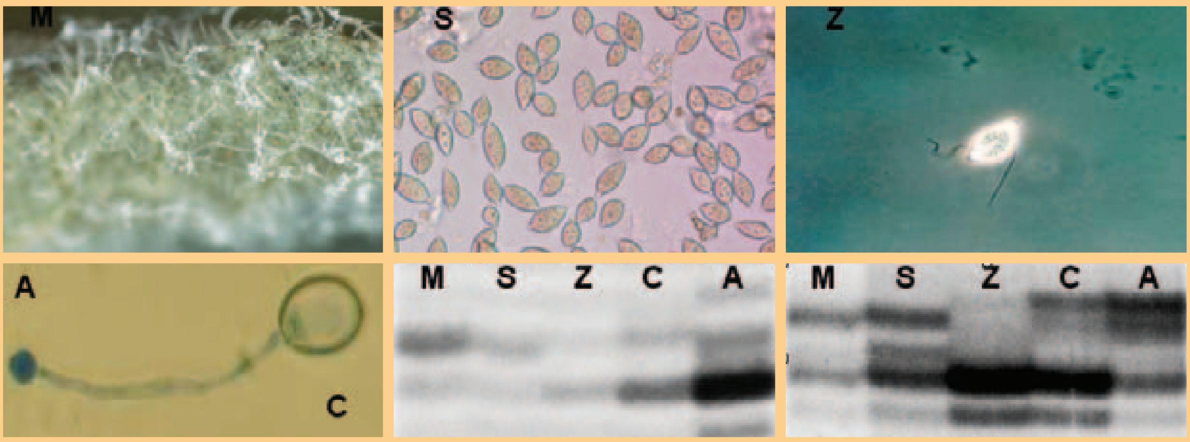

Figure 2 Lifecycle stages in *Phytophthora infestans.* Mycelium (M) forms sporangia (S), that release motile zoospores (Z). The zoospores encyst (C), germinate, and form appressoria (A). Stage specific gene expression can be seen in the sections of cDNA-AFLP profiles (lower right two panels).

in these cell types. Many genes have been identified that can be classified into those required for metabolism, cellular stress, signal transduction, adhesion to host tissue, host cell wall degradation, detoxification and putative virulence factors. Many novel genes, similar to nothing represented in databases, were also discovered. Of particular interest are those genes that encode proteins with predicted signal peptides. These are potentially secreted by *P. infestans* and may interact directly with host plant cells.

Real-time RT-PCR has been used to quantify the relative gene expression profiles for many of the genes identified from cDNA-AFLP and SSH. As expected, all are up-regulated in the cell types from which they were first identified. Many were also shown to be up-regulated to varying levels during the *P. infestans*-potato interaction. For example, glue proteins are expressed at high levels predominantly in those cell types formed just prior to penetration of potato leaf cells. This is in agreement with a hypothesis that some form of sticky matrix is required during the early infection process to prevent the germinated cyst and its appressorium from being dislodged. Of great interest are those genes that showed increasing levels of expression in preinfective cell types, and a high level of expression in the earliest stages of the interaction with potato. In this grouping of genes is a putative secreted small cysteine-rich protein. Genes expressed at these early stages *in planta* are then candidates for influencing the outcome of the interaction. Based on the expression profile for all of the genes discovered to date, they are being prioritized for further functional analyses.

Functional genomics Crucial to understanding the functions of the many genes identified during gene discovery are assays to determine an observable phenotype caused by the presence or absence of specific genes in the interaction. Gene expression vectors based on plant viruses, such as potato virus X (PVX), are being used to express genes predicted to encode proteins with a putative signal peptide; these are known as PEX genes (*Phytophthora* EXported). Infection of potato cultivars containing different resistance genes with PVX expressing PEX genes can reveal if they elicit any response from the potato plants, either in an *R* gene-dependent or *R* gene-independent manner. Plant responses can be observed as either visible symptoms (other than virus infection; Figure 2) or as a specific stimulation of plant defence responses observed through changes in defence gene activation.

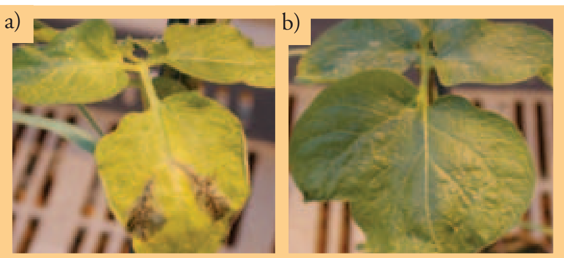

Figure 2 Inoculation of potato with different of *Pex* genes from *P. infestans* cloned into Potato Virus X. a) a defence response has been elicited from the plant. b) No response has been elicited from the plant

Gene silencing has been demonstrated for a small number of *P. infestans* genes through genetic transformation, followed by spontaneous silencing of the introduced copy of the gene. This process, while valuable for determining gene function through its absence, is haphazard in its occurrence and not well suited to the large numbers of candidate genes being generated through any gene discovery program. At SCRI we are piloting a more rapid and transient gene silencing strategy based on the direct introduction of *in vitro* transcribed double stranded RNA (dsRNA) into *P. infestans*. This triggers silencing of the homologous gene in *P. infestans* and is known as RNA interference (RNAi). This technique has been applied to two *P. infestans* genes to date, and initial results have shown a significant gene silencing effect up to 7 days after introduction of the dsRNA. Extended application of RNAi to *P. infestans* functional genomics has the potential to accelerate the determination of gene function.

Future prospects Gene discovery, either targeted (SSH) or not (ESTs), has provided a strong platform for the identification of genes involved in the *P. infestans*-potato interaction. Further strategies for *P. infestans* gene discovery, including microarray analysis of over 15 000 *P. infestans* genes, will add significantly more candidates to the growing list of those for which a function in the interaction must be determined. Improved functional genomics tools, although not as high throughput as gene discovery, are now in place for *P. infestans*. The application of these tools will aid in the identification of genes required for *P. infestans* to be a successful pathogen of potato. Studies of these mechanisms are vital as a counterpart to genomics studies of the host plant potato and its response to infection. Information and insights from both sides of the interaction will better inform future late blight management strategies.

The role of *Potato mop-top virus* proteins in intracellular movement

L.Torrance, G.H. Cowan, S. Haupt and A. Ziegler

To establish a successful systemic infection, plant viruses must move cell-to-cell from the site of infection to the vascular system where they can be translocated throughout the plant. Intracellular movement involves traversing the infected source cell to reach the plasmodesmata (PD), which are small partially occluded pores in the cell walls. PD are the cells' gatekeepers and regulate the passage of macromolecules, facilitating intercellular communication. Plant viruses have evolved several different strategies to locate and pass through PD, which involve one or more virus-encoded movement proteins (MP). If viruses could not move out of the initial infected cell then the plant would not succumb to infection so a study of movement processes may lead to novel strategies for disease control. The aim of this work is to understand how the movement proteins of *Potato mop-top virus* (PMTV) operate and what host factors are involved in the movement process. This research project is done in collaboration with colleagues in cell-cell communication programme.

The PMTV genome encodes a conserved module of three partially overlapping reading frames called the triple gene block (TGB). We study the expressed proteins using several different experimental systems including biochemical characterisation, transient expression in living cells to examine subcellular localisation, and interactions with host proteins using the yeast two-hybrid system. We have shown previously that the first protein of the movement module (TGBp1) binds RNA and the other two proteins (TGBp2 and TGBp3) are integral membrane proteins that interact with themselves and with each other when expressed in the yeast system. The current model of intracellular movement is that TGBp1 forms a complex with viral RNA (vRNP), which is transported to the periphery of the cell and localised to the PD by interactions with membrane bound TGBp2 and TGBp3. However, the precise details of this process are unknown.

The gene encoding TGBp3 was cloned as a fusion to either green (GFP) or red (RFP) fluorescent protein and transiently expressed in plant cells. A fluorescent network was produced on expression of GFP- or RFP-TGBp3 similar in appearance to the cortical endoplasmic reticulum (ER)(see Figure panel a), fluorescence was also observed associated with the perinuclear envelope and in small punctate spots at the cell periphery suggestive of PD labelling. In addition, TGBp3 formed small spots that could be seen moving along the ER (see Figure panel b), this movement was inhibited by the compound latrunculin A, which is known to depolymerise actin.

To try to identify the structures more accurately, RFP-TGBp3 was transiently expressed on transgenic plants where the ER or PD were labelled with GFP. In these experiments, red fluorescence was seen co-localised to the green ER network (Figure panel c). Also, the peripheral punctate red spots produced by RFP-TGBp3 co-localised to green PD (Figure panel

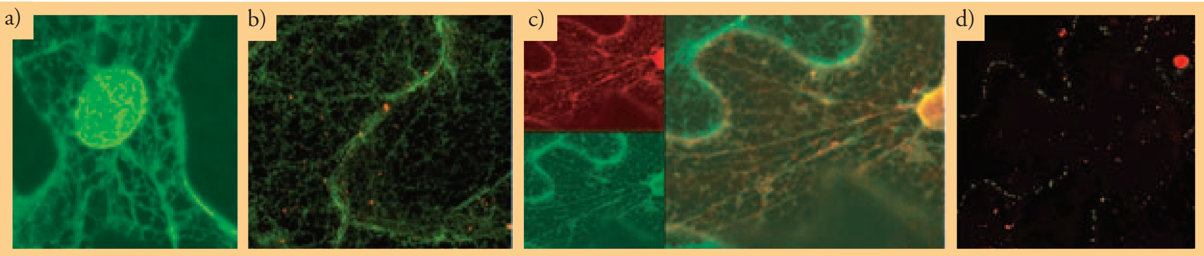

Figure 1 Confocal microscope images of fluorescent TGBp3 fusion proteins expressed in living cells
a) Network of fluorescence and small motile spots obtained on expression of GFP-TGBp3 in *Nicotiana benthamiana* cells b) Small red fluorescent spots seen moving along ER network in cells of transgenic *N. benthamiana* (where ER labelled with GFP) c) Red fluorescent network co-localises to green ER network when RFP-TGBp3 is expressed on transgenic *N. benthamiana* (where ER labelled with GFP) d) Punctate red fluorescent spots co-localise to green plasmodesmata in transgenic *N. tabacum* (transformed with GFP fused to the 30K MP of *Tobacco mosaic virus*).

d). This data suggests that TGBp3 is involved in transporting the vRNP from the sites of virus replication associated with perinuclear and ER membranes utilizing the cortical ER/actin network. Also, that TGBp3 contains a signal to enable PD targeting, either directly or indirectly via other host factors.

Yeast two-hybrid experiments where TGBp3 was used as bait to search for putative interacting plant proteins have revealed an interaction between TGBp3 and a nuclear envelope protein and further work is in progress to confirm this interaction and understand the role it plays in the movement process. Future work will also examine the role of TGBp2, its coordinate mode of action with TGBp3 and identify and characterise key host proteins and receptors that interact with them.

Genes to Products

H.V. Davies, R. Viola & R. Waugh

'Genes to Products' aims to harness the combined power of genomics, contemporary genetics, biochemistry and natural product chemistry to deliver products to market places becoming increasingly sophisticated and competitive. Breeding is seen as a crucial platform for product development but the delivery of high quality, relevant science, is also key to the vision as is the continued development of truly interdisciplinary approaches in problem solving activities. Activities in this Theme will be closely integrated with the development of newly established Product Innovation Centres (PIC) for SCRI's major commodity crops: potato, fruit and grains, each driven by a lead scientist. The PIC falls under the umbrella of Mylnefield Research Services (MRS).

The Genes to Products Theme has two research programmes, Quality, Health & Nutrition (QHN) and Genome Dynamics (GD).

Quality, Health & Nutrition: The goal of the QHN Programme is to implement strategies to improve the quality and nutritional value of raw materials entering the food chain. Traditionally, crops have been bred for high yield and disease resistance. The programme focuses on phytochemicals, which have potentially important roles in human health and on the identification of compounds and processes, which contribute to the flavour and textural properties of food materials. Metabolite profiling has been developed as an underpinning platform technology and is being deployed to assess phytochemical diversity and to unravel the metabolic networks that regulate the development of key traits. The utility of the technology in the detection of unintended effects in GM crops is also being addressed within the framework of national and European consortia.

Research on antioxidants and bioactive molecules focuses on phenolic antioxidants, L-ascorbic acid and carotenoids using a range of phytochemical, biochemical and molecular approaches. *In vitro* digestion studies have shown that fruit anthocyanins are subject to non-specific absorption e.g. on to bile acids and undergo chemical hydrolysis during digestion (and prior to absorption). Significantly, chemical transformations of phenols to ortho-phenolic acids (aspirin analogues) have been detected with substantial biological implications for human health given that aspirin is the leading drug recommended to retard the development of cardiovascular disease. Research on L-ascorbic acid has focused on the plant biosynthetic pathway and turnover in storage organs. In addition, long-distance transport of L-ascorbic acid in crop plants has been demonstrated and novel approaches for the cloning of plant L-ascorbic acid transporters developed. Carotenogenesis in potato has been characterised in detail, focusing on transcriptional changes in genes that encode the major carotenoid biosynthetic enzymes (use of germplasm with high xanthophyll content). Gene targets for the manipulation of tuber carotenoid content have been already identified and functional studies are underway using stable transgenic approaches and, in collaboration with the Cell-to-Cell Communication Programme, viral-induced gene silencing.

Research on organoleptic properties of potato tubers has identified some eighty volatiles produced by cooked samples. Significant quantitative differences in headspace components have been found in germplasm adapted by breeders in the GD Programme, germplasm known to have distinct organoleptic properties. These findings are being exploited to identify the genes involved in flavour generation (cloning, mapping).

Substantial progress has been obtained in protocol development for metabolic profiling using potato tubers as the primary model system for the development of the technologies and assembly of mass spectral databases (GC-MS and LC-MS). Currently *c.* 900 compounds can be separated by combined LC- and GC-MS approaches. The technology is being applied to food safety issues (unintended effects in GM crops) and to determine phytochemical diversity in germplasm collections.

Genome Dynamics: A major objective of the GD Programme is to identify genes (or closely linked markers) controlling important traits in our mandate crops and to use these in the development of improved germplasm. Over the last year significant progress has been made in integrating genomics and informatics technologies and resources with more traditional skills in genetics and plant breeding. The primary molecular tools and competencies exploited are based on the efficient detection and analyses of molecular polymorphism. Throughout the programme, genetic mapping and analyses of the spectrum, frequency and distribution of genetic diversity are being investigated at levels ranging from individual candidate genes, through chromosomal regions to the entire genome. These primary tools have been supplemented by an expanding array of 'genomics' resources such as BAC libraries, microarrays and reverse genetics populations which present new opportunities for understanding the structure and organisation of the plant genome and the transcriptome, and provide a route towards gene isolation and function testing. The tasks of assembling appropriate genetic populations and assaying them for a wide range of important phenotypes are viewed as crucial to our ability to exploit these tools.

The potato research programme is firmly based on the exploitation of the extensive genetic diversity present within the Commonwealth Potato Collection. Last year its conversion into a curated DNA bank with base and working collections of both single plant and accession bulks of DNA was completed. In addition the entire collection (*c.* 1400 accessions and ~600 accessions from the Sturgeon Bay collection in the USA) has been genetically fingerprinted with molecular markers (see following article by McLean, Bryan, Ramsay and colleagues). Importantly, the molecular and phenotypic characterisation of the CPC is guiding its exploitation e.g. in identifying novel, broad spectrum resistance to PCN and novel quality traits. Detailed QTL maps of the two most important sources of resistance to the PCN species *G. pallida* have been developed. Last, but not least, a novel strategy for potato breeding has been published as a culmination of 12 years of research. The strategy is now being introduced into our commercially funded potato breeding programmes.

In the soft fruit research programme, considerable progress has been made in the assembly of enabling technologies for genetics and breeding (informative SSR markers for Rubus and Ribes) and these have been used to construct the first genetic linkage map of the red raspberry *R. idaeus.* Ribes populations have also been developed which focus on fruit quality characteristics which complements the objectives of QHN, our sister programme. These populations have been established as 'living' mapping resources that will be invaluable for conducting the extensive phenotypic analysis required to link genes to phenotypes. The soft fruit programme has had continued success in developing commercial cultivars with new Rubus seedlings combining root rot resistance with fresh market quality and Ribes seedlings with both pest resistance and high ascorbate content progressing rapidly along the route to commercial production.

As a general approach towards the identification of genes controlling traits of interest in barley, considerable progress has been made in assessing the applicability of association genetic studies by developing an understanding of linkage disequilibrium (LD) and some of the factors, which influence it. For example, a detailed investigation across the hardness locus (*Ha*) at the distal end of 5HS has given considerable insight into LD in barley at the ultimate resolution – DNA sequence. These resulting observations are important because they show that such studies are feasible in barley. As a result, LD will be a key approach to candidate gene identification and validation via haplotype analysis. QTL mapping in barley based on composite populations from small progenies from a number of elite crosses has also been initiated. An ongoing objective is the development of SNP and EST-SSR based molecular markers to streamline molecular mapping via population based studies and association genetics.

Two significant contributions have been made towards realising functional genomics studies in barley. Firstly, collaboration with the global barley genomics community has been implemented to exploit the EST collections developed at the SCRI and elsewhere to commission the fabrication of an AFFYMETRIX GeneChip microarray (23,000 unique barley genes). Secondly, to facilitate functional studies on a genomic scale, large, structured mutant EMS and sodium azide populations of cv. Optic and cv. Golden Promise, respectively, have been constructed, evaluated and used for the first time to identify mutations in target barley genes by reverse genetics. There is great potential for using mutants to understand developmental or biochemical processes. Therefore, in addition to the mutant populations, we have developed a series of populations segregating for major morphological mutations as a resource for future gene isolation projects.

Carotenogenesis in potato tubers

W.L. Morris, L. Ducreux, S. Millam, D. Stewart, D.W. Griffiths, C. Lacomme, H.V. Davies & M.A. Taylor

Plant carotenoids are 40-carbon isoprenoids with polyene chains that may contain up to 15 conjugated double bonds. In photosynthesis certain carotenoids have essential functions, acting as accessory pigments in light-harvesting and also as quenchers of triplet excited states in chlorophyll molecules, preventing free radical damage. Due to their bright distinct colours, carotenoids also function as animal attractants and are found in the chromoplasts of fruits and flowers. Plant-derived carotenoids are important in human health. All of the carotenoids that contain a β-ring (most notably β-carotene) can be converted to retinol and, thus are precursors of vitamin A. Additional health benefits of carotenoids are the subject of a growing area of research. For example, zeaxanthin (a relatively rare dietary carotenoid) in combination with lutein are essential components of the macular pigment of the eye and a low dietary intake of these carotenoids increases the risks of age-related macular degeneration. Lycopene, the major carotenoid found in tomato fruit, protects against prostate cancer.

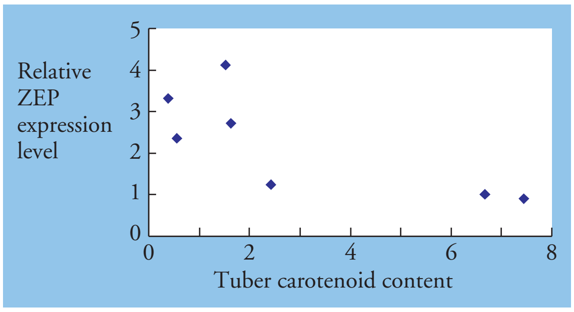

Figure 1 Quantitative real-time PCR reveals an inverse relationship between total tuber carotenoid content and the transcript level of the zeaxanthin epoxidase gene across a range of potato germplasm.

Over the past decade many of the genes encoding the enzymes of carotenogenesis have been cloned from plants. Transgenic manipulation of the carotenoid biochemical pathway has led to notable increases in the carotenoid content and the types of carotenoids produced in a range of crop plants most significantly rice, tomato and canola. Despite these successes however, there is still much to be learnt about the control of carotenoid content in crop plants. In potato germplasm for example, tuber flesh colour ranges from white to yellow to orange, depending on the tuber carotenoid content. The aim of our work at SCRI is to understand the molecular basis for this variation. We then wish to harness this knowledge and explore the limits of how much carotenoid can be produced in a potato tuber and the extent to which we can control the types of carotenoid that are produced. Longer-term we wish to be able to produce significant nutritional benefits in a major staple food.

Our approach has been to carry out a detailed comparison of carotenogenesis in a range of potato germplasm. Tuber carotenoid content is particularly high in a *S. phureja* accession (DB375\1). These tubers accumulate high levels of zeaxanthin and also contain significant levels of antheroxanthin, lutein and violaxanthin. We have demonstrated that tuber carotenoids accumulate during tuber development and the levels of carotenoids remain high during tuber maturation and are stable during six months of tuber storage at 4°C. During this storage phase however, there are changes in individual tuber carotenoid components possibly indicating carotenoid interconversions during storage. In parallel the transcript levels of 14 of the genes encoding carotenogenic activities have been profiled in a range of tuber germplasm during tuber development. Surprisingly we have discovered an inverse relationship between the zeaxanthin epoxidase transcript level and tuber carotenoid content. The molecular basis of this relationship is being pursued in collaboration with the Genome Dynamics Programme. A transgenic approach to manipulating tuber carotenoid content is also in progress. New protocols for the transformation of *S. phureja* have been developed. In collaboration with Cell-Cell Communication Programme we have been successful in developing a VIGS protocol for rapid determination of gene function in potato tubers and this is being used to determine the roles of the genes involved in potato carotenogenesis.

Biosynthesis of vitamin C in plant phloem

R.D. Hancock, D. McRae, S. Haupt & R. Viola

Vitamin C (L-ascorbic acid, AsA) is an essential human nutrient obtained primarily from plants. There is considerable interest in the elucidation of mechanisms responsible for the biosynthesis and accumulation of AsA in crop plants with a view to the development of strategies for optimising the vitamin C content of storage organs such as fruits and tubers. In general, green tissues are known to contain high levels of AsA which plays an important role in photosynthetic activity. On the other hand non-photosynthetic tissues show a much greater degree of variability with no obvious taxonomic explanation. For example, in fruits the variability extends from less than 3 µg gFW^{-1} in the medlar (*Mespilus germanica*) to over 27 mg gFW^{-1} in the camu camu (*Mirciara dubia*). Additionally, environmental conditions and agricultural practices such as fertilisation and water supply are also known to affect the AsA content of crops.

With the objective of optimising AsA accumulation in storage organs we sought to establish whether it is synthesised *in situ* or imported from other sites such as the foliage. Substantial levels of AsA were detected in the phloem of many crop plants by the use of aphid stylectomy, confirming earlier reports[1] and suggesting that phloem transport may be implicated in AsA accumulation in storage organs. Further investigations using courgette fruits, from which copious amounts of phloem exudates can be obtained, revealed the presence of all the known soluble enzymatic activities of the AsA biosynthetic pathway. Evidence of functional AsA biosynthesis in the phloem tissue was obtained with isolated phloem strands from celery petioles. Incubation with the precursors L-galactose and L-galactono-1,4-lactone resulted in up to a 10-fold increase in AsA concentration. Isolated phloem strands were also shown to convert distant ^{14}C-labelled precursors (e.g. [U-^{14}C]glucose or [U-^{14}C]mannose), to AsA more readily than in celery parenchyma.

The unexpected finding of high AsA biosynthetic capacity by the plant phloem raises the possibility that this process may be an important determinant of AsA

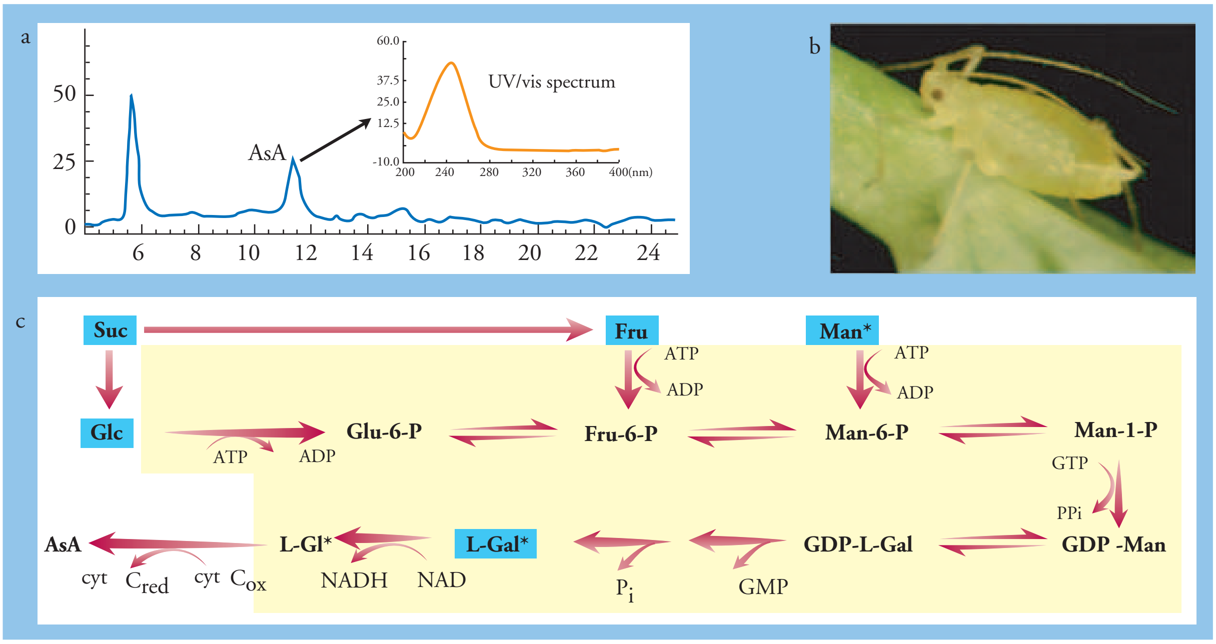

Figure 1 Proposed model of AsA biosynthesis in plant phloem.
High concentrations of AsA were demonstrated in plant phloem (HPLC trace a) by isolation of uncontaminated sieve tube content following stylectomy performed on feeding aphids (b). The inset in panel A confirms that the peak with identical retention time to authentic AsA also has an identical absorbance spectrum. Isolation of phloem exudate from courgette fruit allowed in vitro detection of all known soluble enzymes of the biosynthetic pathway (yellow boxed area in c) and unlabelled and ^{14}C-labelled precursor feeding demonstrated an operational pathway in isolated celery vascular bundles (marked * in panel c). Future work will concentrate on identification of AsA biosynthetic substrates in the phloem (potential substrates are highlighted in blue).

accumulation in storage organs. This hypothesis is at odds with a recent report showing direct AsA uptake and transport in Arabidopsis and Medicago[1]. We have also obtained evidence for L-[1-^{14}C]AsA uptake by source phloem of *Nicotiana benthamiana* but, intriguingly, we have also shown substantial uptake of the AsA biosynthetic intermediates D-[U-^{14}C]mannose and L-[1-^{14}C]galactose. Given the presence of the enzymic machinery for the conversion of these intermediates to AsA within the phloem, the possibility exists that AsA biosynthesis may occur within the phloem *en route* to sink-tissues. The challenge is now to establish which substrate is used for phloem AsA synthesis *in vivo*.

If functionally operational, phloem AsA biosynthesis may represent an important determinant of AsA accumulation in storage organs and a novel target for crop improvement. For example, modulation of phloem AsA biosynthesis would directly affect the AsA content in storage organs of those plants where assimilate unloading occurs via the symplast. Current work (supported by SEERAD, BBSRC, the Blackcurrant Growers Association and GlaxoSmithKline) aims at establishing the relative importance of endogenous synthesis, phloem transport and phloem synthesis to sink AsA content in important crops such as potato and blackcurrant.

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Transgenical approaches to reducing glycoalkaloids in potato tubers

L.V.T. Shepherd, K.F. McCue, W.R. Belknap & H.V. Davies

Steroidal glycoalkaloids (SGAs) are ubiquitous secondary metabolites of solanaceous plants. In potato tubers, accumulation of SGAs confers bitterness and at high concentrations represents a food safety issue due to their toxic properties. High SGA levels can impede the advancement of breeding programs trying to introduce beneficial phenotypes from wild relatives. Potential safety issues surrounding SGA concentrations have led to the establishment of guidelines for maximum SGA levels expected in commercial potato cultivars. Some potentially valuable cultivars, such as Lenape in the USA, have been withdrawn from the market due to a tendency to accumulate undesirable levels of SGAs (in excess of established limits – 20 mg/g fresh weight). *In planta*, SGAs are believed to play a role in pest resistance and can also contribute to potato flavour. SGAs can accumulate in potato leaves and tubers naturally, and their deposition is increased in response to wounding, light and cold storage.

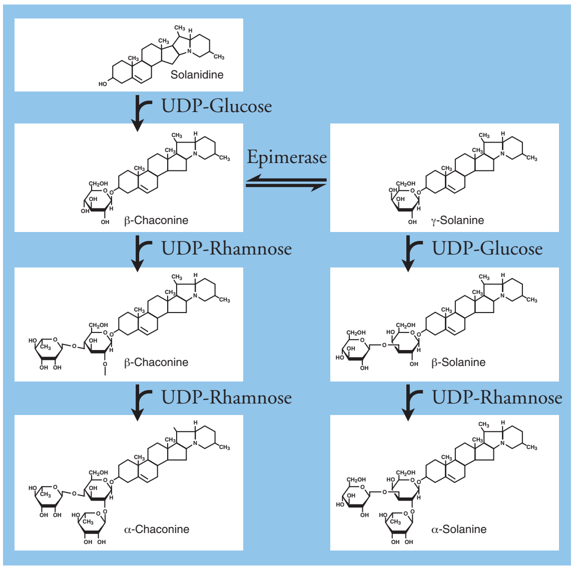

Figure 1 Proposed SGA biosynthetic pathway for the two predominant potato glycoalkaloids derived from the aglycone, solanidine.

Potatoes contain two major SGAs, α-chaconine and α-solanine. Both are triglycosylated steroidal alkaloids derived from the aglycone solanidine, to which either glucose (α-chaconine) or galactose (α-solanine) is added as the primary glycosyl residue. In collaboration with Drs Bill Belknap and Kent McCue at the USDA-ARS (Albany, California) we are studying the impact of down-regulating specific glucosyl transferase genes on tuber glycoalkaloid content and balance using two varieties, viz. Desirée (SCRI) and Lenape (USDA-ARS).

The enzyme solanidine UDP-glucose glucosyltransferase (SGT) catalyses the biosynthesis of γ-chaconine from UDP-glucose and solanidine. While biosynthetic processes leading to mature triglycosylated SGAs are not fully established, the conversion of γ-chaconine to γ-solanine by a specific epimerase would imply that SGT represents the primary pathway for biosynthesis of both major potato SGAs (Fig. 1). At the USDA-ARS, a putative potato gene encoding SGT (SGT1) was expressed in yeast growing on solanidine, and SGT activity of the protein encoded by the gene confirmed *in vitro*. At the SCRI, transgenic tubers of cv. Desiree were produced containing an antisense SGT1 gene driven by the tuber-specific granule-bound starch synthase (GBSS) promoter. This resulted in an almost complete inhibition (*ca.* 90%) of α-solanine accumulation, as quantified by HPLC. However, due to an elevated level of α-chaconine, total glycoalkaloid content was unaffected (Fig. 2), indicating metabolic compensation. The data indicates that whilst SGT1 encodes an enzyme capable of solanidine glucosyltransferase activity *in vitro*, its role *in vivo* is glucosylation of γ-solanine. The tubers are undergoing metabolic profiling using GC-MS and LC-MS to identify the nature of the compensatory mechanism. In parallel (at the USDA-ARS), the same construct was introduced in Lenape cv. with similar results (data not shown). Transgenes containing other putative SGTs are undergoing analysis.

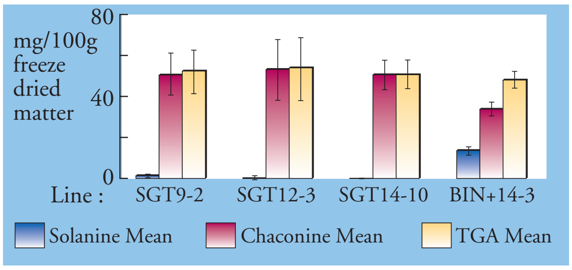

Figure 2 Levels of specific SGAs in tubers of selected second generation SGT1 lines, and an empty vector control (BIN+), as quantified by HPLC.

Retrotransposons and genetic diversity in crop plants

A.J. Flavell, R. Jing, N. Syed, J. Lee & M. Lyons

Only a tiny proportion of the DNA of plants is comprised of genes. The vast majority of the average plant genome is 'non-coding' DNA, most which is made up from transposable elements more popularly known as transposons. As their name suggests, transposons have the ability to jump to new locations in their host genomes. Two major transposon classes exist in nature. The first of these, called retrotransposons or class I transposable elements, move by a 'copy and paste' mechanism, leaving the original 'donor' copy inttact. Class II transposons move by a 'cut and paste' mechanism. Retrotransposons themselves are very diverse, with three major groups identified, called *LINEs*, *copia* and *gypsy*, all of which are found in plants.

Retrotransposons as markers for biodiversity estimation and breeding. Retrotransposons make ideal genetic markers for plants, because they are ubiquitous, highly variable in their locations and very easy to detect. Several methods have been developed for converting retrotransposon insertions into molecular markers and we mainly use two of these, Sequence-specific Amplification Polymorphism[3] (SSAP) and Retrotransposon-Based Insertional Polymorphism[4] (RBIP). SSAP visualises each transposon insertion as a band on a gel and RBIP converts a single insertion into a fluorescent spot on a microarray (see Figure). We use SSAP markers for linkage mapping and biodiversity analysis in barley, wheat, lettuce and pea. RBIP was developed by us to characterise the overall genetic structures of complete germplasm collections, which contain thousands of samples. In the Figure 1536 pea samples, representing one half of the entire John Innes Pisum Germplasm Collection, have been scored for a single retrotransposon insertion. Very recently, we have adapted this method to score Single Nucleotide Polymorphism (SNP) markers.

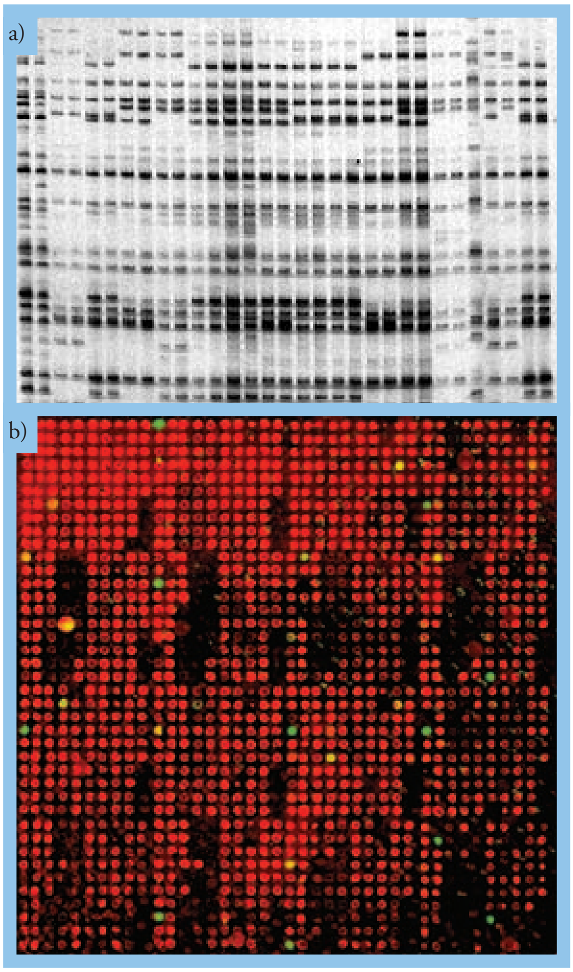

Figure 1 Retrotransposon-based molecular markers. a. *gypsy* SSAP markers in lettuce. Each column is a gel lane from the DNA of a single plant and each band represents a single retrotransposon insertion in the corresponding sample. b. A single *copia*-group retrotransposon insertion was scored in 1536 samples from the John Innes *Pisum* Germplasm Collection. A green spot indicates the presence of an 'occupied' allele (retrotransposon inserted at the locus), a red spot indicates an 'unoccupied' allele (retrotransposon absent from the locus) and yellow spots show the presence of both alleles in the sample.

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Linkage disequilibrium in barley

L. Ramsay, K. Caldwell, J. Russell, M. Macaulay, W.T.B. Thomas, W. Powell & R. Waugh

Linkage Disequilibrium (LD) is the non-random association of alleles at different loci. Such a correlation of allelic states of loci in different parts of the genome is usually caused by the physical proximity of the loci, hence the use of the term linkage disequilibrium although LD can be caused by other factors such as population substructure and selection. LD is of interest as it relates directly to the underlying patterns of polymorphism and therefore affects at a basic level the reliability of diagnostics and the general application of molecular markers to the characterisation of germplasm. Due to availability of molecular markers there has been a renewed interest in LD studies, particularly in humans, that utilize the pattern of ancestral recombination to delineate candidate genomic regions associated with traits of interest such as predisposition to disease etc. In plants such studies have to date been limited and have mainly been carried out in outbreeders such as maize that show similar patterns of LD to those found in human and animal studies. In the Genome Dynamics programme we have been interested in whether such approaches are applicable to barley as such an inbreeding species would be expected to show higher levels of spurious associations due to the relative lack of recombination and the resultant population structure.

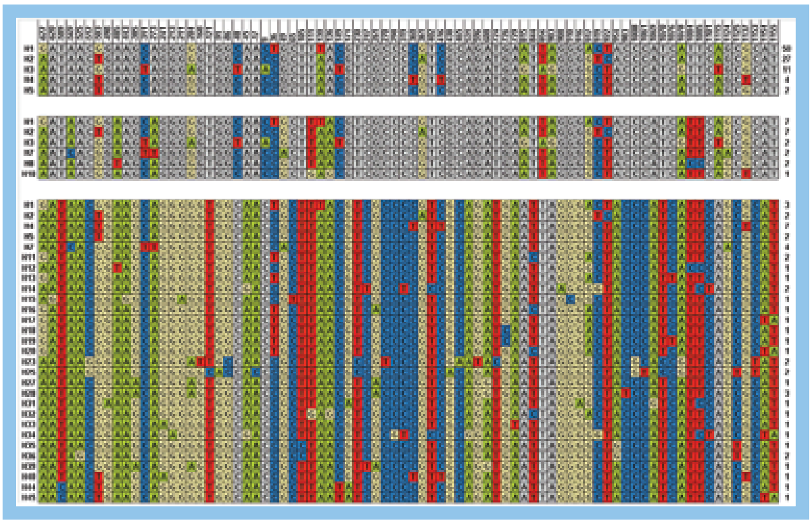

Figure 1 Sequence alignment showing polymorphism at the *Ha* locus

In germplasm surveys of barley cultivars using SSRs (simple sequence repeats) we found significant LD across the whole genome, but that closely linked loci showed significantly higher levels. This pattern was complicated by population structure that could be attributed to past breeding practice in maintaining the distinctness of differing cultivar types. By concentrating the analysis on a single cultivar type (elite two-row spring barleys) the severity of the effect of population structure was considerably reduced though not eliminated. In this elite germplasm the LD observed was maintained between loci up to 5cM apart, considerably further than that found in maize. An encouraging conclusion from these studies was that LD studies are feasible in cultivated barley although care is needed in choice of material and that the use of unlinked marker loci is necessary to estimate population substructure and give empirical thresholds for the appropriate levels of statistical significance.

A detailed investigation at the sequence level of the hardness locus (*Ha*) at the distal end of 5HS has also given considerable insights into LD in barley. Despite a substantial amount of diversity within wild barley, *Hordeum spontaneum*, where over 40 different combinations of polymorphisms or haplotypes were observed, a highly structured pattern of nucleotide diversity across the candidate genes revealed a limited number (4-5) for cultivated lines (Figure 1). Furthermore, the extent and magnitude of LD among these different sample sets revealed radical differences in the maintenance of LD between cultivated and wild barley at the sequence level. In cultivated barley, strong associations were found to extend across the entire 112 kb genic region; however, in wild barley these associations were relatively weak and rarely extended across a given gene. Such differences could prove to be invaluable as appropriate selection of germplasm could direct association studies towards both the location of genes involved in complex phenotypes and the discovery of causative mutations.

Diversity of wild barley in 'Evolution Canyon'

J.R. Russell, R.C. Meyer, C.A. Hackett, P. Lawrence, G.R. Young, B.P. Forster & W. Powell

Lower Nahal Oren is a seasonally dry canyon on Mount Carmel in Israel. Although the geology of the canyon is uniform the opposing slopes, facing north and south, vary substantially in the amount of sunlight received. The south facing slope is hot and dry and characterised by a savannah ecosystem with typically African flora and fauna; the north facing slope is cooler and covered by a dense oak forest with associated European flora and fauna, hence the name "Evolution Canyon". Genetic diversity has been studied in several species in "Evolution Canyon", but wild barley, *Hordeum spontaneum* is of particular interest as it grows on both slopes.

The wild barley population in "Evolution Canyon" has been sampled by our collaborator, Prof. Eviatar Nevo (University of Haifa, Israel) at seven stations on a transect across the canyon: North High, North Middle, North Low, Canyon Bottom, South Low, South Middle and South High. Genetic diversity has been studied using single sequence repeat (SSR) variation in both nuclear and chloroplast DNA of 275 plants. Over 200 alleles were detected for 19 nuclear SSR loci and, in addition, 12 chloroplast haplotypes were detected in the population. A phylogenetic tree was constructed from the data: the branches of all individuals from the north facing slope have been coloured red, south facing slope individuals green branches and canyon bottom individuals blue (Figure 1). The tree shows that nuclear SSR variation in the canyon is non-randomly distributed, as there is a strong tendency for individuals to cluster together according to slope of origin. We have also colour-coded the 12 chloroplast haplotypes red, green, blue etc. and have placed these at the end of the branches of the phylogenetic tree. Linkage disequilibrium is evident between the nuclear and chloroplast data as colour-coded branches and disks match up in the majority of cases. Inter-slope contrasts for chloroplast haplotypes can be seen clearly when the frequency of the two most common haplotypes (red and green) is superimposed on the collection sites in the canyon (Figure 2). The pie charts shows a clear swing in haplotype dominance from one side of the canyon to the other.

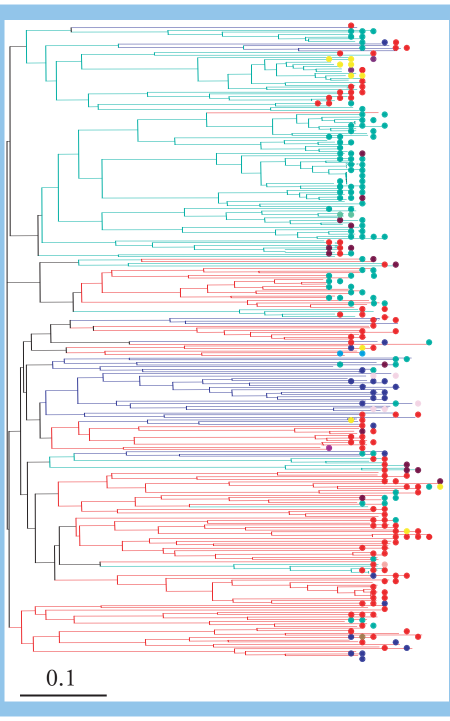

Figure 1 Phenogram of the genetic relationships among seven H. spontaneum subpopulations in "Evolution Canyon" based on UPGMA method branches are coloured based on their slope, SFS (green), NFS (red) and bottom (blue). Chloroplast haplotypes are represented by coloured disks, haplotypes A (green), C (red) and D (blue).

The inter-slope patterns of nuclear and chloroplast genetic variation suggest adaptive divergence to contrasting environmental conditions. Of the two slopes, greater SSR variation was found in the less stressed, north facing slope. In other studies, using anonymous genetic markers such as RAPDs and AFLPs, the opposite was found. The apparent discrepancy is probably due to the fact that SSRs sample a different portion of the genome as they are associated with genic regions. SSRs may, therefore, provide a valuable tool in searching for genes involved in adaptation and species divergence.

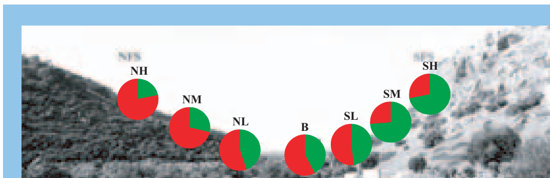

Figure 2 Chloroplast variation for haplotypes A (green), and C (red) in 'Evolution Canyon'.

Utilising Molecular Diversity in the Commonwealth Potato Collection

G. Ramsay & G. Bryan.

As it becomes possible to explore the natural variation in plants at the gene and sequence level, new ways of making precise and effective use of the natural wealth in genebanks become possible. SCRI maintains a genebank of international status, the Commonwealth Potato Collection (CPC). Comprising over 1300 accessions of 77 species, the collection houses germplasm accumulated by collecting missions to S and C America from 1938 onwards. Anticipating this shift in the exploitation of genebanks, we have converted the Commonwealth Potato Collection to DNA form and are preparing for molecular-based exploitation by characterising accessions at the DNA level.

CPC material has been extensively utilised for potato breeding using traditional approaches. An example with great impact on UK agriculture is the exploitation of the H1 gene for Potato Cyst Nematode (PCN) resistance from CPC1673, an accession of *Solanum tuberosum* ssp. *andigena*. Other examples include the use of accessions of *S. demissum* to introgress late blight resistance into cultivated potatoes, and *S. vernei* to introgress a second form of resistance to PCN. These have led to the breeding of disease resistant cultivars such as Maris Piper, Pentland Dell, and Stirling.

Figure 1 Four species in the CPC: *Solanum oplocense, S. cardiophyllum, S. ochranthum* and *S. bukasovii* (clockwise from top left).

Making efficient use of the CPC for potato breeding and other scientific endeavours relies heavily on understanding the relationships of species and the genomes within them. Taxonomies of *Solanum* published to date are generally based on morphological information and where molecular data exist they are frequently from methods with low information content such as RFLPs. In late 2001 we initiated a molecular genetic analysis of the CPC, together with material obtained from other collections in the United States and Peru, using a combination of techniques targeting both the nuclear and chloroplast genomes. Currently we are completing an analysis based on the highly-multiplex Amplified Fragment Length Polymorphism (AFLP) assay, which has involved the deployment of six AFLP primer combinations on approximately 2000 DNA samples, each of which generates in the order of 80-100 AFLP fragments. This study will allow a comprehensive, structured phylogenetic analysis of potato germplasm, leading to the identification of a core collection of material for more detailed genetic, biochemical, and metabolic studies. The data is now helping to generate better phylogenies, throwing light on the origins of species including polyploid hybrid species groups. One particular surprise has been the apparently artificial nature of series Tuberosa.

We have converted the genebank to a curated collection of DNA from both individual seedlings and bulks representing the entire variation in the accession. These resources are now being applied in the search for novel alleles, including those for higher carotenoids and vitamin C, targets which may be amenable to molecular genetic studies of genes for pathway enzymes and controlling loci. Application of direct methods of understanding the basis of genetic variation in these traits will ensure that potato varieties in the future can combine desirable traits in much more efficient ways, and hence supply the products required for future targeted and sustainable food production.

Management of genes and organisms in the environment

G.R. Squire, B.M. McKenzie, D.F. Marshall & A.C. Newton

The year was dominated by the reporting and discussion of scientific results on GM crops and cropped ecosystems. Colleagues were authors in the first refereed papers from the UK's Farm Scale Evaluations of GM herbicide-tolerant crops. Several high-profile reports of our research were published by government on geneflow and persistence in the environment. EU-wide studies were consolidated on the effect of GM plants on soil ecology. Our GM research was recognised internationally to the extent that staff were in demand to advise governmental committees in several EU member states on the potential for coexistence of GM and non-GM crops. Further afield, we ran international working groups through the GMO-Guidelines Project, whose job is to work with national scientists in developing countries to consider whether and how to introduce GM cropping to their production systems. The first two such international workshops were held in Kenya and Brazil. A third is planned for Vietnam in 2004. These varied contributions exhibit the integrative and multi-disciplinary approaches that the Environment Theme can now bring to bear on complex areas of science and its applications.

Firm foundations laid in basic science also brought success in another of the Theme's main specialisms – the effect of plant roots on soil structure and function. A joint initiative in s*oil bioengineering* combines expertise in civil engineering at the University of Dundee with SCRI's biology and biophysics of roots. The partnership has successful widened the range of science-funding bodies to which SCRI can apply. The award of a one-year 'discipline hopper' grant by the Medical Research Council allows us to apply the principles of geotechnical engineering to the biomechanical properties of roots. This was quickly followed by a three-year grant from the Engineering and Physical Science Research Council for more fundamental work on the relations between plant roots and the stability of soil. *Soil bioengineering*'s potential was also recognised by industrial concerns, who have commissioned scoping studies on slope stability, potentially the forerunner of major research funding.

The Theme has also been gearing up for major trans-EU activity in 2004 and beyond. Staff coordinate two EU funded projects on the late blight, *Phytophthora infestans*, one of the most pernicious pests in world agriculture. EUCABLIGHT draws together all European work on the integrated control of late blight; the aim is to reduce the inputs of fungicide by introducing durable blight resistance more widely among commercial potato cultivars. ECOPAPA aims to incorporate durable resistance to late blight into germplasm of the breeding programmes of participating countries, and notably extends operations beyond the EU to Bolivia, Argentina, Uruguay and other parts of Latin America. ECOGEN – the study of ecological and economic impacts of GM crops – is an 8-partner project which examines the integration of GM and conventional varieties in cropping systems, and particularly the effect of GMOs on soil ecology. And most recently, SIGMEA, a >40-partner EU project in which SCRI will manage a major workpackage, aims to draw together all European research on gene flow and persistence in oilseed rape, beet, maize and other crops, then to construct workable predictive models of GM coexistence. This increased networking by Theme 3 in Europe – we now liaise with over 100 groups through these EU projects – enables our science to influence, and be influenced by, researchers in other environments and production systems. We are demonstrating through this work that basic science can be scaled from plant to region to provide sound recommendations that influence the policy of the EU and the care of its managed ecosystems.

Outreach and education Towards the end of 2003, the Theme formed a *Systems Research Group* to expand and exploit its expertise in ecological and environmental research. The Group will apply knowledge of soils, plants, microbes and invertebrates to resolving problems in crop ecology and crop production. Its remit is the 'lowland' or arable production systems of northern Europe, dominated by barley and wheat, and including potato, legumes, brassica crops and soft fruit. The Group will provide a systems context for SCRI's *Product Innovation Centre* for potato, barley and soft fruit. High in its remit is to ensure that SCRI's activities in systems research are fully integrated with complementary studies at related organisations, particularly the Macaulay Institute, SAC and SNH. The first tasks of the Group will combine and apply existing knowledge in four specific, linked subjects - sustaining crop production while enhancing arable food webs, coexistence between conventional, organic and GM cropping , whole-system carbon balance and the recycling of carbon 'wastes', and local impacts on regional processes in epidemiology. The hub of the Group's work is modelling the cropped ecosystem, based on the conceptual and biometrical approaches that were the basis of the MAPP, the *Management Advisory Package for Potato*. Several generic elements of MAPP will form the basis of a flexible framework, notably active influence diagrams that are used in design, development and documentation and a rule-based broker-agent model for flexible, context-specific querying. The *Systems Research Group* is forming links with end-users specialising in plant breeding, farmland wildlife, agronomy, crop protection and land use policy. Together we shall develop a flexible and complementary network of research and advisory functions to tackle emerging environmental issues.

An important part of the Theme's outreach is the *Living Field Project*, which transfers ecological and crop science to schools and the lay public. We have concentrated this year on material aligned with schools' requirements and completed three stages that cover ages 5-11 (A to D/E) of the science curriculum. Staff from the Theme have been much involved in the conception and execution of this resource along with members of SCRI's Scientific Liaison and Information Service (SLIS) and a Primary School teacher who has worked closely with staff to ensure that the CD is relevant, easy to use and fun for pupils. All three stages are being discussed with national and regional education offices and trialled in various schools before launch through digital (web, CD) media by mid-2004. The *Living Field Project* is also being extended to a community garden in the SCRI farm, which also will be ready for visits in 2004 (organised through SLIS); and will be extended to cover the full secondary curriculum.

None of these developments in science, outreach and education would have occurred without the Theme's integrative philosophy that combines disciplines and methodologies linking science to tangible applications at scales of the organism and the landscape. Our approach to GM plants in the environment, for example, combines genetics, whole-plant physiology, community dynamics, molecular diagnostics, seedbanks, entomology, soil-plant relations, modelling and statistics – all of which are in-house and which together inform issues of scientific, public and economic significance. Finally, the turnover of staff through retirements, notably in Host-Parasite Co-evolution, provides an opportunity to concentrate and strengthen our science in areas of epidemiology and disease resistance in crops and other vegetation. A challenging year ahead.

Functional diversity in a model plant community

P.P.M. Ianetta, C. Hawes, G. Begg, G R Squire

Intensification of agriculture has reduced the abundance and diversity of arable plants to an extent that food webs in the arable landscape are losing species and losing function. The biodiversity of arable systems is inextricably linked to their sustained functioning and productivity. If functions such as decomposition and nutrient retention are impaired, the soil-plant system will decline and ultimately collapse. Crop variety and field management can, in principle, be deployed to achieve a sustainable balance between biodiversity and crop yield. To do this needs understanding of the way plant diversity affects other important aspects of the system. However, the species as an accounting unit of diversity is arguably too coarse and hides too much variation. We therefore seek to link the functional properties of the habitat to differences between smaller units such as ecotypes or individual organisms. The approach is systematic and iterative. We define the system's properties, characterise selected individuals *ex-situ*, reconstruct 'communities' of individuals with known traits, test for expected emergent properties and validate on large scales of time and space.

Many of the salient properties of the arable crop/weed/invertebrate system have been studied. They include the architecture of the canopy, the fluxes of resource (e.g. radiation), stores of carbon and nutrients and the structure of plant and animal communities as defined by functionally based groupings (type-accumulation curves, relative abundance and spatial distribution). This phase of the work is near completion for typical crop rotations in northern GB, but function has been quantified only at the level of species. In 2002, we moved to quantify the effects of the differences that occur between ecotypes and individuals. For this we have chosen *Capsella bursa-pastoris* (shepherd's purse) as a model, partly because of its genetic synteny with *Arabidopsis thaliana* but also because it is widespread, economically important as a weed, phenotypically plastic comprising several distinct ecotypes and contributes to the arable food web. Individual accessions were taken throughout GB and phenotypically characterised in controlled environments. The ecotypes can be separated, e.g. by nitrogen content, flowering time, vegetative traits and reproductive capacity. New statistical approaches are used to quantify the life-cycle trajectory of each accession. Genotyping (SSRs) distinguishes the different ecotypes and will be developed to explore the connection between phenotypic and genotypic variation.

For the next stage, *Capsella* ecotypes, each with defined traits, were assembled at a 'patch' scale in the field during 2003 in different combinations, at different population densities and within various weed assemblages. An indicator of an emerging system-property is the total branch length of a dendrogram for plants in a 1m^2 plot based on many physiological traits. (Fig. 1 shows a dendrogram for three traits, plant height, leaf number and rosette diameter.) This preliminary estimate of functional diversity is now being related to the abundance and biomass of associated insects (herbivores, detritivores, pollinators, predators and parasitoids) caught by suction sampling. The mechanisms linking plant traits to diversity and abundance in the food web are being investigated.

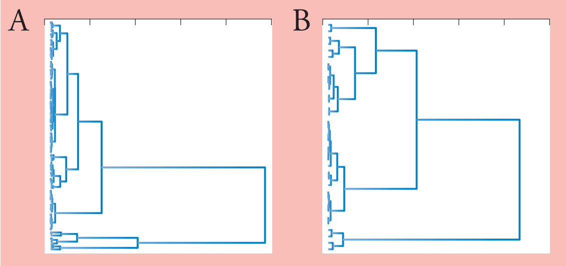

Figure 1 Cluster analysis of two populations each in 1m^{-2} of field, characterised by three physiological traits. Functional diversity is proportional to total dendrogram length. Plot A (a single ecotype) has lower dendrogram length and therefore lower diversity than plot B (a mixture of 2 ecotypes).

The effects of these fine differences between ecotypes of *Capsella* will be combined with existing coarser knowledge of the 70 or so commonest arable plant species. The effect of plant traits on the food web will then be predicted at scales of the field and over several years of cropping. Inferences will be validated by reference to large, existing data sets on arable diversity and to measurements made later in the project on a range of crop/weed communities. The final outcome of the project will be a design for a workable arable system that balances crop production and biodiversity.

Field to field geneflow in oilseed rape

D.W. Cullen, J.N. Anderson, J. McNicol, G. Ramsay, G.R. Squire

An important topic in European agriculture is the coexistence of conventional, organic and GM farming. For coexistence to be feasible, transfer of genetic material between crops would have to be kept below stated thresholds. If gene movement between fields happens only at low frequency and over very short distances, then different types of farming should be possible within small areas of land (e.g. 10 km^2). However, if gene flow occurs above, say, 0.3% and over several km, then coexistence may only be possible by segregating types of farming into different regions. Progress is limited by a lack of sensitive detection techniques for measuring pollination at low frequency in the very large samples that are required to estimate out-crossing between whole fields in the landscape. To remedy this, the UK government has funded a four-year project to measure gene movement between fields, to determine how the type of receiving crop affects the result and to explore ways to minimize gene movement. The project is run by six organizations – SCRI, Rothamsted Research, CEH, CSL, NIAB and ADAS – who between them have the necessary range of disciplines, laboratories and field sites.

The major challenges in the first two years are to devise sensitive techniques for detecting very low pollination-frequencies and to characterize the spatial variation of pollination over fields. The first task was to select donor and receptor varieties for developing the detailed methodologies. For preliminary analysis, a high erucic acid (HEAR) type was chosen as the donor and a low erucic (LEAR) type as the receptor. The key enzyme in erucic acid biosynthesis in *Brassica* species is the product of the Fatty Acid Elongation 1 (*FAE*1) genes, β-keto-acyl-CoA synthase (KCS). The trait is controlled by two highly homologous genes BN-FAE1.1 and BN-FAE1.2, corresponding to the parental species *B. rapa* and *B. oleracea FAE*1 genes. Mutations in these genes are responsible for the low erucic trait of LEAR types. To explore the variation in these genes, DNA was extracted and analysed for >90 varieties of *B. napus* and other *Brassica* species. Small differences between donor and receptor sequences were found in the form of a 2-base and a 4-base deletion in the BN-FAE1.2 gene sequence of the receptor. The differences were considered sufficient to be able to detect pollination from HEAR to LEAR types and a real-time PCR assay has been developed using these deletions as markers.

Plot experiments were set up in 2002/03 to test insect-capture techniques at Rothamsted and to estimate low frequency pollination in an isolated plot at SCRI (Fig. 1). Donor and receptor fields were then sown at both sites for measuring gene movement over short and moderate (1 km) distance in 2004. Subsequent objectives are to confirm the most suitable donor and receptor types for large-scale studies and to develop assays based on real-time (TaqMan) quantitative PCR for high-throughput screening of samples. The project scales up in 2005 and 2006 to examine low-frequency geneflow over several kilometers in arable regions throughout the UK. The final outcome of the work will be recommendations to policy-makers and growers on what is needed to achieve economic coexistence of conventional, organic and GM farming where oilseed rape is used as a break crop. The preliminary results are already informing several EU member states who are defining or implementing their own policies on coexistence. The project is funded by Defra/SEERAD and coordinated at SCRI.

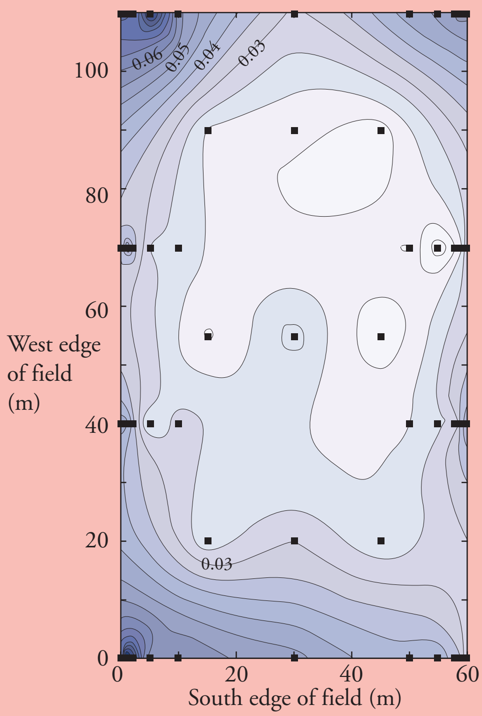

Figure 1 Contour diagram of low-level gene flow into an isolated plot of male sterile oilseed rape, showing greater pollination at the corners and edges.

Plant root biomechanics and slope stabilisation

P.D Hallett, A.G. Bengough, O. Hamza[1], M.F. Bransby[1], M.C.R. Davies[1] & C. Halpin[2]

Plants root systems have evolved into complex engineered structures capable of mechanically supporting a large shoot mass above ground by forming a biological anchor in the surrounding soil. Roots also have a huge capacity to reinforce soil, increasing slope stability and the resistance to physical degradation. Although it is well accepted that roots are extremely important to these processes, surprisingly little is understood about the mechanical interaction between soil and roots. This presents challenges to crop production, the safety of slopes (particularly along transport corridors) and the ecological restoration of degraded soils.

One example of the economic significance of this problem is crop lodging, which cost British farmers £120 million during a particularly bad season in 1992. New cereal varieties have been bred with shorter stem lengths to reduce lodging, but it may still occur through the rupture of the root system. Tree blow-down is also affected by the capacity of roots to act as an anchor. Landslides following forest clear-cutting have highlighted the importance of vegetation to slope stability. A new industry, often referred to as 'Soil Bioengineering', advocates the planting or maintenance of specific vegetation on potentially unstable slopes, to reinforce soil. This may help reduce the £40-50 million annual expenditure incurred by Network Rail maintaining earthworks along the UK railway network. Ongoing maintenance to clear trees beside railway lines may decrease problems with 'leaves on the line', but the implications for slope stability are not certain. Slope failure caused 30 train accidents in the UK in 2000. These problems are predicted to worsen with climate change, due to the increasing variability of rainfall and greater frequency of more intense rainfall.

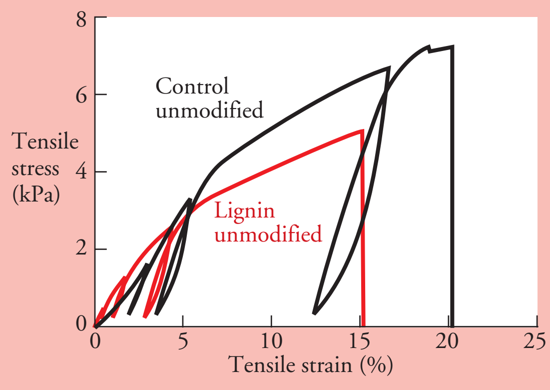

Figure 1 Mechanical behaviour of tobacco roots under tensile strain.

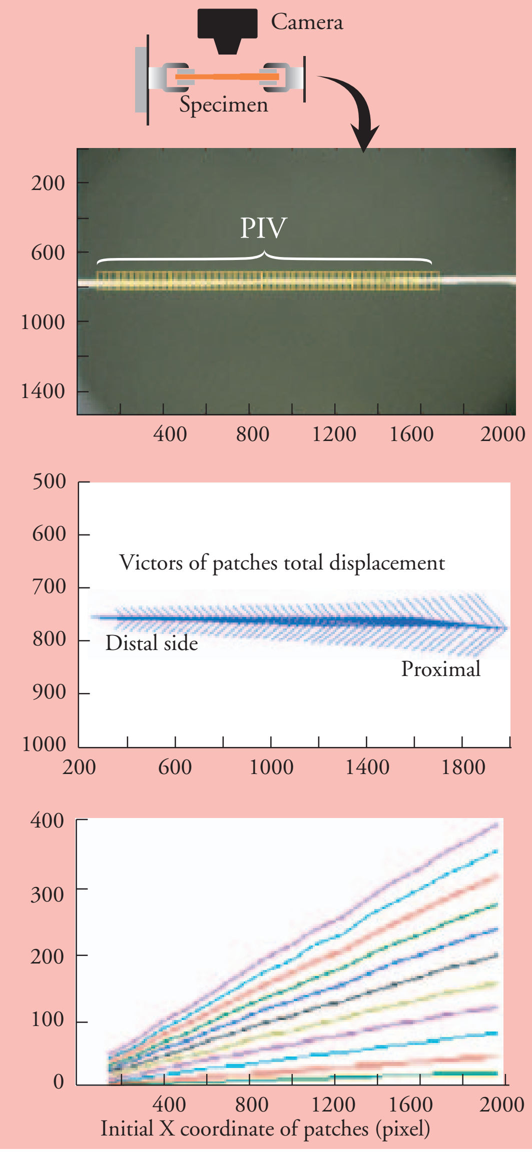

Figure 2 Particle image velocimetry (PIV) allows us to detect localised strain fields that are common in biological material. High quality digital photographs are taken as the root is stretched under tension. Patches placed over the image are analysed to detect any movement, which relates to the deformation of the root as it is stressed.

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[2]School of Life Sciences, University of Dundee

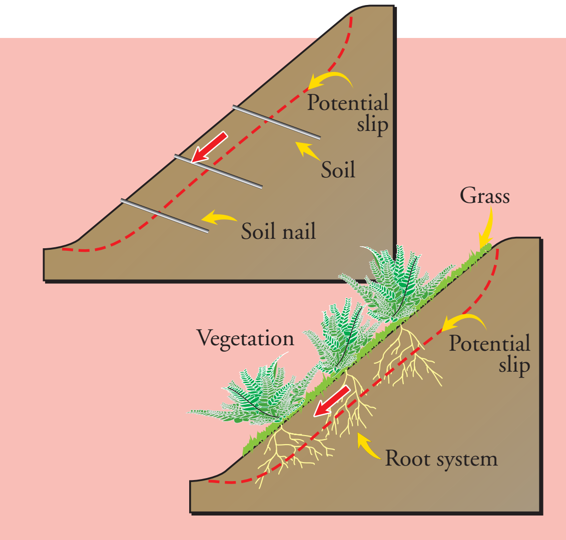

Figure 3 Roots can reinforce soil in a similar way to soil nails by bridging potential slip surfaces.

Through research collaboration with the University of Dundee, we are investigating plant root biomechanics and the use of roots to improve slope stability. Recent advances in geotechnical engineering, developed primarily for understanding the reinforcing effect of soil nails and micropiles, are being used to understand the mechanical interaction between roots and soil. We believe that by using complex constitutive equations of soil mechanical behaviour, combined with numerical approaches, accurate predictions of root-soil mechanical interactions are possible. This is a technological leap from the previous research that relied heavily on engineering approaches based on simple assumptions that were developed almost 40 years ago.

The research ranges from a genetic level understanding of root biomechanics to predictions of large scale slope instability. Model plant systems are being used to understand the biomechanics of individual roots. By suppressing 1 or 2 specific genes in tobacco, Dr Halpin has produced plants that differ only in the composition and abundance of lignin. Reduced lignin density alters the mechanical behaviour of roots (Figure 1), thereby providing an ideal model system to quantify the influence of genetics and cellular structure on root biomechanical behaviour.

Funding from the Discipline Hopper scheme (MRC/EPSRC/BBSRC) has allowed a University of Dundee geotechnical engineer, Omar Hamza, to work exclusively on applying geotechnical engineering to plant root biomechanical behaviour. Particle image velocimetry (PIV) has shown the localised strain fields that develop in mechanically stressed roots under tension (Figure 2). Both cellular rupture that controls root strength and slip planes that affect root pull-out from soil will be affected by localised strain. We believe that this is the first time that PIV has been applied to the tensile testing of materials. The technique may prove useful to a wide range of other applications, including medical biophysics and materials science and will be used to study root-soil interaction later in the research programme.

A new project funded by the EPSRC will examine the stabilisation of slopes with plant roots. Figure 3 illustrates the similarity between plant roots and the use of soil nails for slope mechanical reinforcement. This part of the project seeks to investigate the link between root systems, root mechanical properties and soil slope stability. By testing slopes at small scale on 1 m^3 models (but at the correct stress levels, using a geotechnical centrifuge), slopes will be brought to ultimate limit (i.e. "failure") and serviceability limit conditions so that the exact reinforcing effect of the vegetation can be quantified. In addition to testing real root systems, the creation of reduced-scale root analogues will allow different root architectures to be investigated sequentially. Ultimately the work will provide a quantitative basis for making recommendations for the design of root stabilised slopes. It will also provide an experimental basis for future modelling studies and the selection of plant varieties for improved slope stabilisation.

Our unique collaboration aims to provide both agronomic and engineering solutions from a strong base of fundamental science. An industrial steering committee has been formed to help direct us towards practical applications and facilitate the rapid dissemination of new knowledge. We have already received considerable interest from industries concerned with the management of vegetation on steep slopes.

Microbial and microfaunal variation in soils

B.S. Griffiths, R.E. Wheatley & T.J. Daniell

The drive towards so-called sustainable agriculture means a greater reliance on biological processes in soil. The term ‘sustainable’ is usually not well defined but in relation to agriculture means a move towards lower inputs (of fertilisers and pesticides) and greater in-field diversity of above-ground species. The key to such systems is what happens below-ground, in the soil, as biological processes and populations here drive soil nutrient flows, influence emergent plant communities and affect the outbreak of soil-borne plant diseases.

Understanding how spatio-temporal variations affect N-cycling within an arable context will enable efficient management of sustainable eco-systems. Potential nitrification rate (PNR), defined as the oxidation of ammonium-N to nitrite-N, was studied during the growing season of barley (*Hordeum vulgare* L. c.v *Optic*). PNR showed considerable spatial and temporal variation throughout the sampling period (Fig 1). There was a 500-fold variation in PNR during the season and a variation of up to 2.5 times at any single sampling. We are presently investigating the drivers of this microbially-mediated function with DNA/RNA techniques linked to simultaneous function estimations.

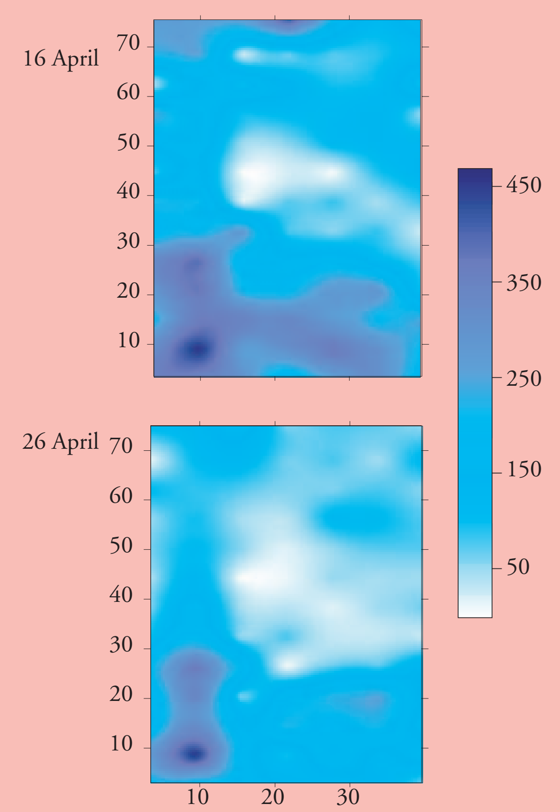

Figure 1 Concentration contours of nitrification activity (0 – 450 µg NO_2-N g^{-1} soil h^{-1}) across a barley field (70 x 30m) on two days in April.

We are also investigating the role of denitrification (the conversion of nitrate to nitrogen oxides, therefore a loss of valuable fertiliser and a source of potent greenhouse gas) in the same arable systems. To understand the biodiversity associated with this process we have applied a high throughput sequencing approach to a key functional gene in bacteria (*Nir*K) that controls denitrification. We have exhausted the common sequence types in three arable fields at SCRI, as shown in the phylogenetic tree (Fig. 2). Nitrification and denitrification are linked microbial processes and we are, for the first time, now able to link biodiversity and activity on a spatio-temporal scale.

Microbial activity in soils is regulated to a large degree by the animals that eat them, which in arable soils are

Figure 2 Neighbor joining tree (F84 model with gamma rates) of NirK sequences from arable fields, upland grassland and database sequences. Terminal taxa are representatives of clustering at 0.075 substitutions per base. Blue = Arable types, Red = Upland grassland types from a separately funded project, Purple = Database examples.

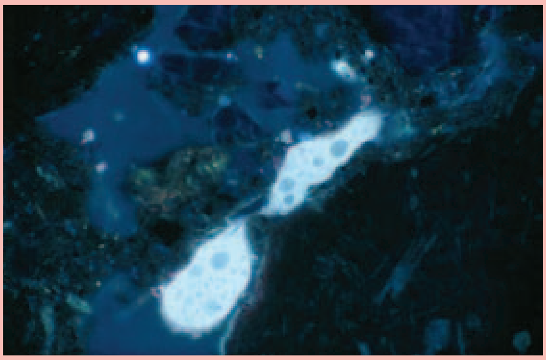

Figure 3 A thin-section through soil showing an amoeba traversing a soil pore.

mainly protozoa (Fig. 3) and nematodes (Fig. 4) and recent work within PSI has confirmed that microbial community structure in soil is significantly affected by both nematodes and protozoa (Fig 5).

Figure 4 Bacterial-feeding nematodes from soil.

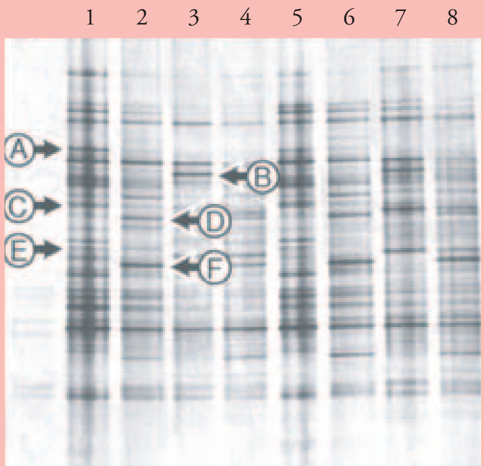

Figure 5 DNA banding patterns of the microbial community as affected by the presence of protozoa and nematodes. Bands A, C and E are absent from treatments with protozoa (lanes 3,4,7,8), B only appears in treatments where protozoa are present (lanes 3,4,7,8), and bands D and F only appear where nematodes are present (lanes 2,4,6,8). Lanes 1 and 5 are treatments with bacteria only.

Whether there is a specific relationship between grazing fauna and bacterial composition will be important in understanding microbial dynamics in the rhizosphere of arable crops.

The aim of the microbial ecology research within the programme is to enhance the sustainability of arable agricultural systems through understanding and manipulating soil biology.

The role and importance of canopy heterogeneity

A.C. Newton, G. Bengough, G. Begg, J.S. Swanston & C. Hawes

Most crops grown in western agriculture are monocultures; genetically identical individuals grown over extensive areas. This is an effective strategy for maximising yield in a high input, high profit, low risk agricultural system. However, where profits are minimal and impact on the environment of the inputs is 'costed in' then the strategy may be inappropriate. Genetic uniformity leads to vulnerability if the cost of inputs is too high to maintain profitability as such monocultures have less resilience to stresses whether from climate, weather and soil conditions (abiotic factors) or pests and pathogens (biotic factors), whereas heterogeneity leads to increased resilience to stress, so lowering risk.

Most natural ecosystems comprise a great diversity of genotypes at all taxonomic levels, each occupying a niche with both spatial and temporal attributes in dynamic balance. By inference single genotypes do not exploit the environmental resources available to them as effectively. While there is great potential for breeding single genotypes to much more effectively utilise resources available in the absence of competition, the potential is constrained by the total genome complement available in a single individual, excluding exploitation of temporal and spatial heterogeneity between individuals. Furthermore, selection to exploit particular resources frequently results in loss of ability to exploit others. In a heterogeneous community, by definition there is more variation present and therefore more potential for optimum response to changes in resource availability. Modern varieties selected for maximum resource exploitation in intensive agriculture may not be successful in heterogeneous communities if appropriate competitive traits have been lost. The nature of the interaction between plant genotypes therefore needs to be understood in order to ensure enhanced resilience to stress and beneficial productivity in both single genotypes and heterogeneous combinations.

Plants do not simply compete with other plants. Plant leaves and stems create an environment or canopy in which many other organisms live. This environment can be very heterogeneous, providing niches for a diversity of organisms from other plants and plant saprophytes, to parasitic, saprophytic and symbiotic arthropods and microorganisms. The environmental niches will vary in traits such as wetness, humidity, light quantity and quality, nutrients, temperature and morphology. Changes in canopy structure can result in considerable differences in the community of organisms they support.

Rhynchosporium secalis is the fungal species which causes 'scald' or 'leaf blotch' on barley and is common in many regions. It is splash-dispersed, first from the soil where spore inoculum survives on crop debris, then from leaf to leaf as it forms necrotic lesion and sporulates. An open canopy will enable rapid transmission by rain splash up the plant. Epidemic progress can be reduced by molecular and morphological mechanisms. Genetic resistance results when specific genotypes (races) of the pathogen are recognised by plant defence genes causing induction of resistance expression mechanisms. However, if the host plant has only a single recognition gene then the pathogen will mutate to produce new races not recognised by the pathogen. Multiple host plant genotypes with many different recognition genes prevent this becoming a problem, particularly as complex races capable of avoiding all recognition genes are normally less 'fit' and will therefore not survive as well. Morphology can be manipulated by affecting plant height and leaf angle, and by providing a complex canopy structure disrupting vertical splash dispersal pathways for pathogen dispersal. Multiple contrasting morphological types are particularly effective in this.

In a natural community plant genotypes are very unevenly distributed in terms of numbers and spatial distribution. Understanding these patterns is critical to understanding the stability or resilience of the system. To mimic this in order to obtain the benefits in agriculture we are limited by available genotypes and technology such as seed drill design. However, we can at least vary the component number and the proportions of the components. It may also be possible to distribute the components in an even or patchy structure at a range of scales. Patchiness may be important in creating 'refuges' for pests not adapted to multiple components of the mixture, and the size and distribution pattern of such refuges, particularly their connectivity, may be critical for stability of the system. The optimum structure will depend upon the 'objective' and, for example, for disease control it will differ

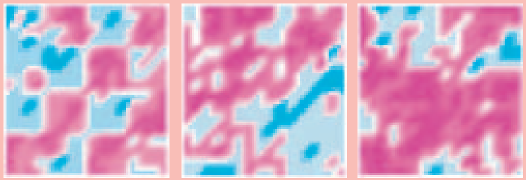

Figure 1 Disease progression (*Rhynchosporium secalis*) over successive times showing lessening effect of underlying 4 x 4 plot host (barley) planting pattern.

depending upon the dispersal characteristics of the pathogen and its population structure.

The structure of a crop canopy has the potential to influence the invasion, establishment and spread of insects through a field. Homogeneous canopy structures that have high levels of connectivity between stems and leaves may allow a rapid spread of herbivorous insects, thereby increasing the likelihood of pest populations reaching threshold levels. In addition, the dynamics between pests and their predators may be destabilised by this rapid population growth due to the lag in development of predator populations relative to their prey. If heterogeneity in canopy structure causes a reduction in the apparency of the plants to the herbivores, the plants have a refuge from insect attack and the population growth of the pest may be reduced. Introduction of sufficient heterogeneity in canopy architecture to impede the movement of herbivores without significantly affecting that of the predators may enhance the potential for natural biological control.

Within-field heterogeneity is not only an important consideration for management of pest populations, but also for management to increase plant and invertebrate diversity. Increased canopy heterogeneity can result in greater diversity of associated herbivores and their natural enemies through the provision of a range of niches where direct competition for resources can be avoided. We have shown that the diversity of insects associated with the weed flora was greater than that associated with crop plants, and the diversity of predators was greater than that of their prey. In general, weed plants hosted up to ten times as many invertebrates per gram of plant material compared to the crop. Within-field plant diversity is therefore important for management of pests and to enhance diversity at higher trophic levels. This may be achieved either by allowing the development of the weed community to within acceptable limits according to the competitive ability of the weed population, or by creating a mixture of a range of different crop genotypes.

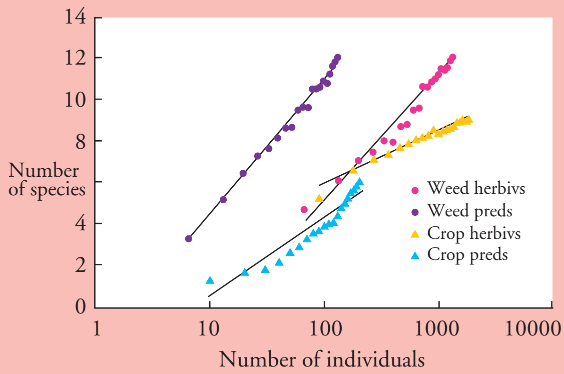

Figure 2 Figure showing greater diversity (steeper slope of the species-accumulation curve and higher intercept) in insect herbivores and predators associated with weed flora (heterogenous structure) compared to those insects associated with the crop vegetation (homogenous structure, OSR)

Below ground, soil resources of water and nutrients are very patchily distributed. As much variation is often reported within the root system of a single plant as exists across a small field. Plants compete with their neighbours for these resources, and their effectiveness in doing so depends on their ability to grow a root into the resource patch, and the relative sink strength of the root for the resource. Hence, the interaction between root distribution, soil resource distribution, and the uptake efficiency determines the ability of plants to uptake water and nutrients, resulting in effects on the above ground canopy environment. We are studying both the genetic variation in root traits (Forster et al., 2003), and modelling the effect of root distribution and soil structure on uptake. There is potential to choose appropriate complementary root systems within a crop mixture to give a robust yield, whilst minimising nutrient loss.

In the context of agriculture, compromises have to be reached between environmental or ecological considerations and the economics of food production. A yield of the quantity and quality required by end-users must be delivered in a timely and cost-effective way. However, the customer is not always right, and in some instances a compromise in some of their requirements may give them unforseen benefits in other areas whilst also satisfying the requirements of others further up and down in the supply train. We addressed an example of this in a previous article (Newton & Swanston, 1998) showing how better malt can be produced from barley mixtures. Another example is illustrated by the difficulty of combining desirable traits within a single cultivar. The yield of alcohol obtainable from a sample of malt is determined by two factors, extract (the total soluble material) and fermentability (the proportion that yeast can convert into alcohol). Both factors are controlled by a number of genetic factors and, on one chromosome segment, desirable expressions for the two characters were shown to be linked in repulsion (Meyer et al., 2001). In this case, selection for optimal levels of extract could mean inheriting a gene that adversely affects fermentability whereas they can be combined in mixtures. This also illustrates the potential value of trait-associated markers in the the design of mixture.

In conclusion, heterogeneity in canopy structure should be seen as an asset to be exploited to achieve practical, sustainable agriculture. As long as variation around an acceptable mean for the harvested product is comparatively small, end-users will not detect significant problems and if the buffering effects of mixtures reduce the environmental component of variation, acceptable levels of homogeneity should be readily obtainable. The reduction in requirements for pesticides from more balanced crop ecology, and the productivity gain from better resource utilisation, are self-evident benefits.

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EUCABLIGHT and ECOPAPA

A.K. Lees & J.M. Duncan

Eucablight and Ecopapa are EU funded projects concerned with research into Late Blight (caused by *Phytophthora infestans*), a devastating disease of potato foliage and tubers.

Eucablight (A Late Blight Network for Europe): This Concerted Action, with 24 partners in 14 countries is co-ordinated by SCRI and runs for 3 years from Feb 2003. The project aims to bring added value to late blight data that already exists at a national level, through common interpretation and analysis at a European scale. For example, the integrated control of late blight with reduced inputs of fungicides could be improved if durable blight resistance was more common in commercial potato cultivars. Many sources of resistance exist, but the nature of that resistance is often poorly understood. This project uses collective expertise to compare existing practices and to suggest new standardised procedures that will allow objective comparisons of genetic resources. Currently, the European data on host resistance in Europe is fragmented, and the methods used to collect it are not well documented. We will collate such data into a readily accessible database to allow breeders and geneticists to compare or exploit sources of resistance in breeding programmes. In turn, the effective deployment of resistant commercial cultivars creates a "moving target" for *P. infestans* and can only be effective if we understand the existing pathogen population structure and can predict its ongoing evolution. Studies to date have focused on national isolate collections, and a comprehensive pan-European assessment of blight populations was lacking. Sexual reproduction is blurring the boundaries between well-defined strains and new co-dominant markers will be applied to meet this challenge. This project tackles the clear need for European standardisation and is successful in fostering international collaborations between European laboratories and also on a global scale with institutions such as GILB (Global Initiative on Late Blight) and CEEM (Cornell-Eastern Europe-Mexico International Collaborative Project in Potato Late Blight Control). For more information visit www.eucablight.org.

Ecopapa (Enrichment of potato breeding programmes in Latin America and Europe with resistance to late blight): The main aim of this project, which ended in February 2003 was to incorporate durable resistance to late blight into germplasm of the potato breeding programmes of the participating countries, especially Bolivia, Argentina and Uruguay in order to stimulate the development of new resistant cultivars. Material from SCRI was rated highly for foliage and tuber blight resistance when trialled at several sites in Europe and South America. The breeding programmes of the partners were strengthened by the addition of exchanged material, and by the fact that this material has been evaluated for resistance at many locations and in two years. The development of markers for resistance is expected to be completed by the end of 2003. The project successfully trained additional staff, principally from South-America in using molecular markers. In addition, SCRI was responsible for phenotypic and molecular fingerprinting of *P. infestans* isolates from the participating countries: similarities and differences between pathogen populations in the six countries have been clarified, which gives indications of the value of using accessions from the different partners'countries, and on the possibilities of targeting new cultivars to more than one region.

Both these projects illustrate the added value of European and Worldwide collaborations that focus on clear strategic objectives and work together towards the integrated control of potato late blight.

Figure 1 Participants at the first annual meeting of 'Eucablight' hosted by SCRI in October 2003.

IOBC GMO Guidelines Project

A.N.E. Birch & R.E. Wheatley

The GMO Guidelines project is an international initiative of public sector scientists to establish scientific tools and methods to assess potential environmental impacts. The IOBC GMO Guidelines Project has an important goal in which international and scientifically acknowledged guidelines and methods will be developed to evaluate risks posed by the cultivation of genetically modified organisms. The guidelines are drafted by the project core group of more than 200 public sector scientists from 26 countries and around 100 public sector institutions, including SCRI. Dr Nick Birch leads the group on "Non Target and Biodiversity Impact" and Dr Ron Wheatley leads the subgroup on "Soil ecology". During the project scientists are invited to participate actively in the discussion and to present their ideas for developing the guidelines. These are being developed and tested with local scientists and invited external experts at three workshops; in Kenya (Bt maize case study; November 2002), Brazil (Bt cotton case study; June 2003) and Vietnam (Bt cotton and rice case study; April 2004). Full reports and summaries of the workshops will be published in at least 2 books by CABI, sponsored by UNEP-GEF-STAP for international distribution.

What are the GMO Guidelines?

They consist of:

- •Inter-linked modules of scientific questions related to risk assessment and corresponding scientific methodologies.
- •Advice to regulatory authorities, who can choose to implement parts or all of the guidelines.
- •Designed for use on a case-by-case basis and before approval is given for GM release.
- •Cover both environmental and agricultural impacts of GMOs, applicable to most GM crops.
- •Do not cover human health impacts or ethical implications.
- •Presently focused on Bt crops as specific case studies, but will later be developed into generic guidelines.

The scientific scope of the Guidelines is divided into five sections:

- •Problem formulation and options assessment.
- •Transgene expression and locus structure.
- •Non-target and biodiversity impacts.
- •Gene flow and its consequences.
- •Pest resistance management.

The project is coordinated by an international Steering Committee of 14 scientists and policy makers. There is also an Advisory Board, comprised of representatives from international and national organizations who have the scientific expertise to critically advise the project, and who can influence the adoption of the guidelines internationally.

The list of contributing institutions can be found on the website below.

The first two GMO workshops (Kenya, Brazil) have provided illustrative and contrasting agricultural, climatic, socio-economic and ecological situations. Although the main case study crop in Vietnam will be the same as in Brazil, Bt cotton, a different transgene construct will be investigated, and cultivation conditions are very different. The project gratefully acknowledges funding from the Swiss Agency for Development and Cooperation (SDC) and the International Organisation for Biological Control (IOBC Global).

For further details see: www.gmo-guidelines.info.
www.gmo-guidelines.info.

Figure 1 Brasilia Workshop June 2003.

EST Bioinformatics

D. Marshall, L. Cardle & P. Shaw

A major change to the information landscape in which we operate for most of our key crop and pathogen species has occurred over the last 2-3 years as the result of a dramatic change in the volume of available sequence information. This is true both for organisms themselves and for the key model organisms which form a major comparative genome resource.

For this account we will focus on barley and potatoes. The major contribution has come from a number of large scale EST (Expressed Sequence Tag) sequencing programmes, though a small amount of BAC-scale genomic sequence is also becoming available in both species. This has generated some 370,000 barley and 132,000 potato ESTs (See dbEST current EST statistics at: http://www.ncbi.nlm.nih.gov/dbEST/dbEST_summary.html). These resources are leading to a dramatic change in working patterns in molecular biology and to an increasing role for bioinformatics within the institute's research programmes.

EST sequencing programmes rely on a philosophy based on a relatively 'quick and dirty' approach which involves single pass sequencing of ESTs from a range of cDNA libraries. This is usually 5' sequence though individual clones may also be sequenced in the 3' direction. Such single pass sequences then form the template for a range of subsequent molecular biology and bioinformatics activities. The first stage after the removal of low quality sequence and vector contamination is to obtain an initial indication of function through homology searches against a range of public databases using the Blast suite of programmes. The second step is to carry out sequence assembly which uses software tools such as CAP3 to assembly the EST sequence fragments into contigs and then subsequently derive consensus sequences. The high redundancy level of EST sequences from relatively highly expressed genes and the occurrence of cDNA clones truncated at the 5' end together lead to the generation of consensus sequences which are both of surprisingly high quality and much longer than the individual single pass EST sequences.

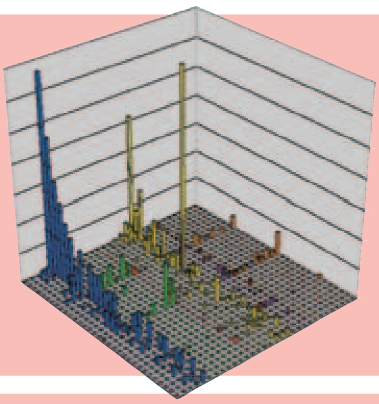

Figure 1 Data from 31 barley EST libraries chosen to show the relative abundance of the most highly abundant expressed endosperm sequences across a range of other tissues

Within the Computational Biology Programme at SCRI we have built up a considerable expertise in the process of EST sequence assembly and the use of the subsequent assemblies and consensus sequences as the substrate for a whole series of downstream activities ranging from the identification of Simple Sequence Repeat (SSR) and Single Nucleotide Polymorphism (SNP) genetic markers, expression analysis (based on microarrays, SAGE analysis and electronic Northerns - see Figure1) and for the identification of barley and potato orthologues of genes that have been characterised on other species especially in model organisms such as Arabidopsis.

The task we face in helping develop the EST sequence resource from potato and barley as a major tool in our research is confounded by the continuing generation of new sequence information as well as the rate of change in sequence annotation, especially due to the progress of functional genomics in Arabidopsis and rice as well as more directly in barley and potatoes. To meet this challenge we have adopted two main approaches. The first of these is to develop a relatively lightweight scalable database infrastructure based on a combination of public domain software tools and applications tools, including MySQL, PostgreSQL, Perl and Apache. This has now been applied to a series of database applications both for day to day support for individual research programmes and as a central resource for internal and external interaction with SCRI data resources. Examples may be seen though the SCRI Bioinformatics web server at http://bioinf.scri.sari.ac.uk/. The second major activity has been to develop strong relationships with a number key of information providers. These include the Graingenes, Gramene and BarleyBase cereal databases in North America. A key aspect of our involvement has been to highlight the importance of data quality and data validation in comparatively map and sequence analysis and the promotion of appropriate informatics standards.

Mathematical modelling

B. Marshall

Models are an intricate part of our everyday life. We use them to make decisions in the belief that taking certain actions will probably result in particular outcomes. The underlying models are simplified but effective "pictures" of reality. Likewise, models are the cornerstone of scientific method. A model is essentially a hypothesis, a statement of how something works or interacts, which is tested by its predictions. Its truth can never be proven, since it can always fail the next test. Newtonian Mechanics was believed to apply in all circumstances, but ultimately failed in conditions extreme compared to our everyday experience. Nevertheless, much of our modern world still exploits the models of classical mechanics because the predictions remain accurate in the world we live in.

We use the familiar to describe the unfamiliar. We define things by their behaviour and by analogy. The electron with a fixed mass and charge, could be thought of as a minute billiard ball. These properties are exploited in the domestic TV. However, it also exhibits wave like properties. Imagine waves entering a harbour. They emerge within as circular wave fronts and with two entrances, close by, produce the familiar patterns of interference. Exactly the same patterns were seen when a single electron was "aimed" at a much smaller pair of slits. This means the electron "passed" through both slits at the same time, which seems surprising if you only think of electrons as particles. Electrons are both like particles and like waves.

Aristotle was a keen observer, especially of biological systems, and emphasised the importance of considering the whole. He believed the "physical method", promoted by Democritus, failed because it tried to explain things by decomposing them into their parts and ignored the whole. Knowing that a house is built of bricks, mortar and timber tells us little about its architecture and nothing of its purpose. Similarly, reducing an animal or plant to its parts and ignoring the whole tells us nothing of its form or function. Aristotle believed that the study of nature should focus on the coordination of the parts in the whole and this is never more applicable than today. The behaviour of the system as a whole is referred to as an emergent property. It is not a property of the component parts but a consequence of the interactions between them. The Gas Laws are a classic example – the temperature, pressure and volume of a gas are related by a simple rule. Boyle discovered this rule, an emergent property, by making measurements at the scale of the system. If he had been able to break down the gas into its components, to see the molecules in-situ, then he would have observed them moving in random directions, at different speeds and occasionally colliding (interacting) with each other and the walls of the container. He would have seen nothing of the large scale behaviour of gases. Only by modelling these interactions could he then possibly predict the emergent property. In ecological systems we face this challenge. It is easier to observe the individual than

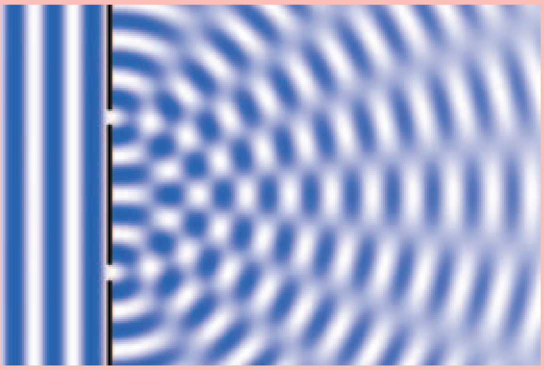

Figure 1 An electron is both like a particle and a wave. A single electron passes through both slits at the same time producing interfering waves on the far side, like waves of the sea passing through two entrances to a harbour.

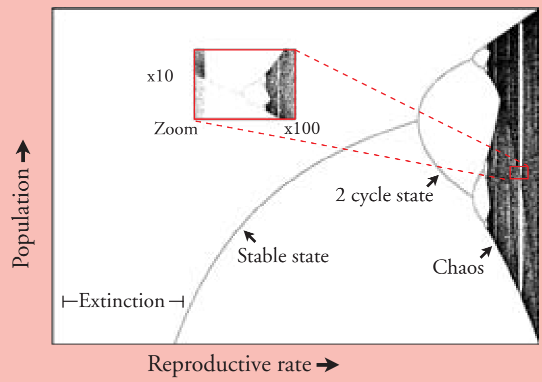

Figure 2 Steps to chaos. The behaviour of a population with a limited food resource can change dramatically if the reproductive rate of the individuals is altered e.g. a different species or warmer temperatures.

Figure 3 Frost on a windscreen. Simple mechanisms can create rich, life like patterns.

the whole. If we are to predict the future survival of an ecosystem accurately then we must capture the key interactions between individuals.

Much of nature is non-linear and yet much of mathematics is dedicated to linear problems, because analytical solutions can usually be found to the linear problems but rarely to the former. The power of computers has enabled us to explore non-linear systems in much greater depth. Rich and complex behaviour can emerge from the simplest of non-linear systems. An example of this is the chaotic behaviour that can arise from a simple but powerful ecological model of population growth. The population grows in proportion to its size, initially doubling in each life cycle. However, the population as a whole has finite food supply. As the population expands, food becomes limited and rates of mortality exceed those of birth. The behaviour of this model is critically dependent on the reproductive potential of the individual. For low values, mortality always exceed birth rates and the population becomes extinct. For moderate values, stable population densities are reached. At higher rates, the behaviour changes dramatically from a single stable population to cycling through sets of fixed densities: first one bifurcation, where the population oscillates between two densities on alternate life cycles, and then more bifurcations. Each doubling requiring smaller and smaller increases in reproductive potential until the system becomes "chaotic". In chaos, the population is constantly changing at each life cycle and never revisits an earlier density. Although chaotic, the range of densities is restricted and some regions are more likely to be visited than others. The behaviour seems random but is not. In principle, if one knew the population precisely at one point in time then one could predict all future populations. The problem is that the smallest error in this estimate is rapidly magnified over a few life cycles and predictability lost. This behaviour is an intrinsic property of the system and not caused by any external, fluctuating influences. Weather exhibits similar changes in behaviour, moving from relatively stable states where long term-forecasts are reliable to more turbulent, chaotic states where forecasts are limited to a day or two and with much less confidence.

Models are simplified representations of reality with the ability to predict. We often use the familiar to describe the unfamiliar, but must be wary of any preconceptions and assumptions made. It is important to consider the whole, how the components interact, in order to discover the emergent properties of a system. We must be aware that even the simplest biological systems can exhibit a rich behaviour – an apparent population crash may be an intrinsic property of the system rather than an indication of an external, adverse influence. We aim to combine mathematical modeling with biological experimentation while keeping an open mind when studying systems.

Biomathematics and Statistics Scotland (BioSS)

D.A. Elston & J.W. McNicol

Biomathematics and Statistics Scotland (BioSS) contributes statistical and mathematical expertise to the SEERAD-sponsored research programme. BioSS staff are based in Edinburgh, Aberdeen, Ayr and Dundee to facilitate close collaboration with scientists at the five SABRIs and all three SAC sites. BioSS research is carried out under three themes, namely 'Systems Modelling and Risk', 'Spatial and Temporal Models' and 'Statistical Genomics and Bioinformatics'. The last of these is led from SCRI, and was the subject of a workshop with our French counterparts, INRA's Département de Biométrie et Intelligence Artificielle.

Detection of putatitive recombinant sequences in multiple alignment data has been the target of three statistical methods developed at SCRI during recent years. With the appointment of a Bioinformatics programmer, we started to develop a Java-based graphical interface, called TOPALi, to these methods that would run on all computer platforms. The initial version allows plotting of the graphs in real time, and the estimation and visualization of phylogenetic trees. Our future plans include the automation of many aspects of the analysis. BioSS also increased its efforts in Microbial Genomics via a joint BioSS/SCRI PhD studentship to analyse the newly sequenced Erwinia carotovora genome. Initial work has been on the detection of regulatory elements using existing statistical methods, including Weight Matrices and Hidden Markov Models.

In linkage disequilibrium mapping, a model has been developed to simulate the flow of genetic markers through a plant breeding population. Our aim is to create a simulated barley population to see if the reduced recombination rate in barley makes the method feasible for detecting traits of economic interest. The model estimates the proportion of heterozygotes, allele frequencies and Hardy-Weinberg equilibrium in each generation. The results of the model are consistent with genetic theory, with linkage disequilibrium decaying at a rate that is proportional to the selfing rate and homozygosity increasing under selfing.

The link between vegetation and microbial community structures in upland grassland received an increased BioSS involvement with the start of phase III of the SEERAD funded Micronet project. As well as designing sampling strategies, geostatistical and multivariate methods were used to identify the extent and scale of coupling between soil microbial communities and plant species in upland grasslands. This work has been extended to investigate the effect of arbuscular mycorrhizal fungi on rhizoplane bacterial community structure.

Image processing and analysis were used to identify void and solid space in soil samples and geostatistical tools were used to describe the spatial distribution of voids within highly heterogeneous images of soil aggregates obtained using X-ray microtomography at the Advanced Photon Source, Argonne National Laboratory, Chicago

Under the heading of ecosystem management, a model was constructed to investigate the processes responsible for the persistence of genetically modified (GM) oilseed rape volunteers and to predict the impurity that would result in subsequent crops. A stage-structured, life-history approach was taken which also includes the effect of various management practices on persistence and contamination. The simulated oilseed rape populations are subject therefore to a set of life-history processes and events associated with the management of an arable rotation that in combination dictate the growth rate of the volunteer population. Results from the numerical analysis of the model indicate that stringent control measures would be necessary to suppress GM volunteer populations sufficiently to achieve the EU thresholds for the adventitious presence of GM material

Analysis of metabolic profiles has become an increasingly important aspect of the BioSS contribution to the Quality, Health and Nutrition programme at SCRI. We have adopted the approach of analysing each compound individually by analysis of variance and summarising the results by simple significance plots for main effects and interactions. We also use principal components to examine how the compounds react in combination with each other, and plot the component scores against the individual compound values to identify the relationships among compounds, components and experimental treatments.

Research services

Analytical facilities

C.M. Scrimgeour

Organic Mass Spectrometry. SCRI currently has six mass-spectrometers interfaced to gas or liquid chromatographs for sample separation. The Hewlett Packard 5989B MS ENGINE GC-MS is a research-grade quadrupole instrument with electron impact, chemical (positive/negative) ionisation modes and a mass range of 2000 amu. Distributed processing software permits off-line data processing and reduces analysis times. This instrument can provide mass and structural data on a wide range of organic compounds. The analysis of volatile compounds uses a Markes International Unity and dual Ultra automated thermal desorption system (ATD) linked to a VG TRIO-1000 quadrupole gas chromatograph-mass spectrometer and permits detailed characterisation of profiles of organic volatiles generated by biological systems. The most recently purchased GC-MS instrument is a ThermoQuest TEMPUS-TOF, capable of rapid detection, characterisation and quantification in fast GC separations. The design provides parallel mass analysis with a short duty cycle at high transmission. This delivers rapid acquisition and fast sampling of narrow peaks at high sensitivity with high sample throughput suitable for metabolite profiling.

The Finnigan SSQ 710C dedicated liquid chromatography-MS instrument, with atmospheric pressure chemical ionisation (APCI) and electrospray ionisation (ESI) interfaces is suitable for samples whose high molecular weight, lack of volatility or polarity, make HPLC the preferred separation method. The multi-charge ionization mechanism of electrospray can extend the basic 2000 mass range of the instrument by a factor of about 20, giving a mass range of greater than 40,000 amu, suitable for protein analysis. Two ThermoQuest LCQ-DECA, ultra sensitive ion-trap LC-MS^n systems are capable of many more scan functions than the SSQ710C spectrometer, including data-dependent full scan MS/MS, a tool of great utility in high throughput profiling.

Isotope ratio mass spectrometry. SCRI is equipped with modern instrumentation for stable isotope analysis of the biologically important light elements, ^{13}C, ^{15}N, and ^{18}O in a wide range of solid, liquid and gas samples. All the instrumentation is based on continuous-flow isotope-ratio-mass spectrometers that are fully automated and operated through computer data systems, allowing a high through-put of samples, essential for many biological experiments where large data sets are required. For solid samples, the Europa Scientific Tracermass and 20-20 mass spectrometers are interfaced to Roboprep CN and ANCA-NT SL combustion sample converters. A Roboprep G+ gas purification unit is used for gas analysis. Analytical protocols are devised to minimise sample preparation and fully exploit the automation.

Gas chromatography. Within the MRS Lipid Analysis Unit and SCRI, gas chromatographs (HP 5890 and Agilent 6890 systems) are used primarily for fatty acid, sterol and leaf wax analysis but are also used for developing separation methods for GC-MS studies. Laboratory facilities are available for extraction and derivatisation of a wide range of samples.

Quality assurance. Within SCRI, the Gas Chromatography-Mass Spectrometry Laboratories, Stable Isotopes Facility and Lipid Analysis Unit of MRS Ltd, operate a formal Quality System certified to BS EN ISO 9001 by SGS Yarsely International Certification Services Ltd. The certification standard was upgraded from ISO 9002 to ISO 9001 in August 1999, and now includes the design and conduct of research within its scope.

Figure 1. ThermoQuest TEMPUS-TOF.

Media Kitchen

W. Ridley

The Media Kitchen was established in 1996 to provide a wide range of sterile microbiological, mycological, plant tissue culture, media preparations and disposable plasticware for the Institutes' laboratory staff.

The advantage of buying in bulk has meant huge savings, and prices have fallen as the volume of orders has increased. The Media Kitchen operates as a research facility under the central administrative overhead, to minimise bureaucracy Centralising the media preparation has meant that individual departments no longer have to maintain a sterilisation and media preparation facility.

The Media Kitchen is staffed by two full-time and one part-time members of staff. The facility is supported by the efforts of one full-time and one part-time worker who were initially recruited from The Helm Project in Dundee.

Orders are delivered on a daily basis to 13 pick-up and drop-off locations around the Institute. At the same time, used media kitchen glassware is collected to be washed and recycled. Empty tip-boxes and eppendorf pots are collected to be refilled. This work is carried out primarily by the support workers. They also, on a separate run, collect, autoclave and dispose of waste microbiological materials.

Agar plates and any other specific media can be ordered by e-mail, telephone or by visiting the Media Kitchen. All requests are usually met within 24hours.

Figure one shows the output of the Media Kitchen, year by year since the first full year in 1997. From these figures it would appear that saturation point has been reached but with University staff just moving into the Institute and changing patterns in science this could change.

The Media Kitchen quickly outgrew its original premises and moved to much larger premises at the end of 2000. This much-improved working environment has given us greater diversity i.e. the pouring by hand of slopes and different sizes of plates. It also means that we can carry much larger stocks of the most popular media which relieves the pressure when we are short-staffed either through annual or sick leave.

The work that is carried out by the Media Kitchen staff not only frees the innovative scientists, visiting workers, Phd students and the support technicians from the repetitive and time-consuming tasks associated with media preparation, it also guarantees a standardised quality of media according to ISO 9000. This was attained in November 2002 and will prove invaluable as regards grants and contracts.

The facility and service the Media Kitchen offers is appreciated and often envied by visiting scientists and students. The provision of a standardised, quality-assured media and sterile disposable-ware facility, with its daily delivery service and daily removal of waste microbiological materials will continue to be invaluable both to researchers and to those monitoring costs and assessing value for money.

	1997	1998	1999	2000	2001	2002
Boxes of tips (100/box)	13,933	14,300	19,738	19,653	20,609	24,000
Eppendorf tubes (*c.* 200/pot)	2,600	2,620	4,211	4,279	4,130	4,561
Agar plates	37,011	43,600	56,084	52,064	51,349	50,974
Other items *	24,654	45,080	47,928	51,850	43,389	43,180

* Item = anything bottled and capped.

Figure 1 Media kitchen output.

Division of Finance and Administration

N.G. Hattersley

The Division is responsible for the provision of the 'non scientific' services to the Institute and encompasses the Units of Engineering and Maintenance, Estate, Glasshouse & Field Research, Finance and Human Resources, Information Technology and Scientific Liaison and Information Services, including Health & Safety, employing a total of 78 staff.

The Division provides a comprehensive service to the scientific community to ensure that they have the resources and ability to carry out research, and that the infrastructure meets all requirements in terms of statutory legislation and health and safety. The variety and sophistication of the work carried out at the Institute continues to increase and the staff within the various Units have responded to this.

The Division is an integral part of the Institute and often provides a breadth and depth of practical experience that is not available elsewhere. The Estates and Glasshouse Unit provide a service ranging from the planting and monitoring of a wide range of agricultural and horticultural trials on the Institute's 400 acres of farmland to the provision of sophisticated facilities in both glasshouses and controlled environment facilities. In doing so they produce consistent, high quality results for scientists despite the vagaries of the Scottish climate.

Similarly the Engineering Unit has to maintain the basic infrastructure of the Institute whilst having to adapt it to meet the needs of increasingly sophisticated (and expensive) equipment. The Institute was very successful in attracting £2.5 million of capital grant from the Scottish Executive Department of Environment and Rural Affairs, which was extremely welcome but had to be managed by the Unit, within an already tight staffing and finance budget. Much of the new equipment requires more sophisticated support and maintenance, and the staff have become extremely adaptable and knowledgeable, whilst continuing to maintain a wide breadth of facilities within a structure that, other than glasshouses, has not changed substantially in the last ten years.

The Institute is increasingly reliant on its computer systems. As such, the IT Unit and its development is central to the Institute's activities. New staff have been appointed and, building on the investment in the IT infrastructure in earlier years, the Institute plans to invest in an Institute wide information management system to allow it to manage the ever increasing flow of information, provide IT the environment for staff to manage their work, to enable staff to develop the Institute web site, and to allow them to disseminate their work.

In this, staff are also assisted by the Scientific Liaison and Information Services Unit who are tasked with raising the Institute's profile, strategic management of the site, and promoting the science of the Institute to as wide an audience as possible, with particular emphasis on schools. This has been assisted by the appointment of an Education Officer, supported by the Mylnefield Trust. The quality of the displays, posters and presentation is remarkable given the size and resources of the Unit.

The provision of a safe and healthy working environment has always been one of the priorities of the Institute and the Mike De,Maine, the Institute's Safety Coordinator works closely with the Engineering Unit and all other departments within the Institute to ensure all requirements are adhered to and that a culture of safe working is promoted throughout the Institute. This will be further developed with the increased implementation of procedures under the ISO 9001 standards.

Underpinning all of this is the Finance and Human Resources Unit, which works to ensure that all the administrative processes run as smoothly as possible and that the Institute operates within the available funds by providing relevant and timely financial and management information. Similarly, the HR staff support the Institute staff in all aspects of their work, training and personal development, including accreditation under the Investors in People initiative. Employment legislation and statutory requirements continue to increase and the HR Unit will require to keep pace with such developments.

The Division has to carry out its work within tight financial constraints but the staff approach their work with an enthusiasm and dedication which demonstrates their commitment to the work of the Institute.

Development and Scientific Liaison and Information Services (SLIS)

I. Kelly

This year saw the completion of the planned changes in SLIS. Much more of the routine organisation of the Unit's work is now devolved to Sarah Stephens (looking after science communication and the library) and Ian Pitkethly (looking after Visual Aids and the web site). A new Education Officer, Sharon Neilson, has been appointed to a full time position.

Significant work was undertaken on the planning of the SCRI Science Park and in developing links into Europe. The Institute joined Scotland Europa.

In terms of science communication, press and visitor related activities the Institute has:

- given over 30 public lectures
- participated in 4 science festivals, garden shows, etc. to take our science to the general public
- hosted over 1,300 individuals and groups of visitors
- welcomed local primary and secondary teachers and their pupils to the Institute
- produced 288 refereed and 184 non-refereed papers and articles in the past year

One measure of our impact is the 194 plus press references to SCRI's work.

Politicians continue to appreciate the importance of SCRI's research. We have hosted MPs, MSPs, MEPs and local Council representatives. We continue to liase with the Information Officers from the other SABRI's, SAC and RBGE and to contribute to reSEARCH, the newsletter of SEERAD's Agricultural and Biological Research Group.

Staff changes in the Visual Aids section reflected the changing nature of presenting information. Two graphic designers and a photographer offer a contemporary professional service to illustrate and record the work of the Institute. Assistance and training is also provided for scientific members of staff who prepare their own visual material. The newly appointed web developer has designed a new web site, integrated with the new SCRI information management system, which will continue to evolve.

The acquisition of electronic journals by the Library has continued to increase this year. The SCRI Library has joined consortia with other research libraries to increase bargaining power. In this way we provide, at the researchers desktops, access to the complete content of Elsevier's science journals through ScienceDirect and Blackwell Publishing's Synergy service as well as to the Nature Group of journals, and Science. These services are heavily used by the staff.

The move towards open access publishing is very slow. While researchers are rewarded for the number of papers they publish in journals with a high impact factor, the commercial publishers will continue to benefit from publicly funded research. The Librarian is looking at the various options for open access publishing to provide SCRI scientists with further avenues for publication of their research.

The appointment of a full time Education Officer to work with teachers, other educators and organisations, is allowing SCRI to develop a wide range of activities and resource materials aimed at encouraging young people to take an active interest in science in general and plant science in particular. The Institute is an active partner in the Dundee City STEM Partnership and works closely with the Dundee Science Centre. This new appointment is unique within the SABRI's.

The end-users in agriculture, horticulture and biotechnology continue to take a great interest in the Institute's research and, indeed, support aspects of it through their membership of SSCR. Information is disseminated through the Annual Report and through Crop Walks for soft fruit and potatoes (the latter in conjunction with SAC and BPC) that attracted 50 and 300 visitors respectively in the year 2002.

SLIS will continue to evolve in three areas:

- to develop and deliver key strategic Institute initiatives such as the Science Park
- to provide quality scientific communication, visual aids, library, web and media services
- to work with our SABRI colleagues in science education and science and society

Information Technology

S. Clark & B. Marshall

The year began with an overhaul of the IT suite. Benches were constructed in the user area, populated with eight flat screen Dell systems - two with scanners. Furniture and carpeting were replaced and a projector screen installed from the roof, creating an IT training area. A PC set up and maintenance corral, a separate alcove to house the central printers, and additional office space were built and the remaining offices redecorated. The computational biology programme is now alongside IT. Finally, a secure server room was constructed with air conditioning, computer cabinets and heavy duty shelving. The efforts of Engineering and Maintenance are much appreciated.

The decision was made to install Windows XP pro OS on all new desktops while leaving existing desktops on Windows NT. Staff received training in the new OS, which has lived up to its reported improved functionality and reliability. The Standard network operating system, Novell Netware v3.12 was upgraded to v5.1, providing many advantages, not least a reboot taking a matter of minutes, not the 45 minutes with v3.12! Two Dell servers were purchased, one as standby should the main server irrecoverably crash. Back up strategy was enhanced with a central facility for all the Institute's systems. The main Unix fileserver was replaced with a faster, larger capacity system. Network management tools were purchased to observe network performance and rapidly troubleshoot problem devices.

Cygnet Solutions Ltd were commissioned to design and implement SIMS (SCRI Information Management System). There were four key requirements: reduce the amount of paper based administration, manage documentation better, improve collaborative working and increase the use of web content to publicise work externally. The solution has a new platform, Windows 2000 Advanced Server running MS Exchange and Sharepoint Portal Server on separate machines. Activedition was chosen as the content management system for both internet and intranet sites. The first prototype of the Portal was rolled out to a pilot group in spring 2003 followed by the new internet site.

Honours projects continued with the University of Abertay, producing three excellent outcomes. In the first, students created new search, management and data submission web-pages for DRASTIC (http://www.drastic.org). In the second, Living Field, the students created a prototype web-site aimed at primary schools. This has been well received and should be ready for release in 2004. The third involved T-RFLP (Terminal-Restriction Fragment Length Polymorphism), a high throughput, genetic fingerprinting technique that quantifies the proportions of micro-organisms present in a sample, used in studying effects on the diversity of microbial populations. The students produced an award winning, Visual Basic program that automates this complex search.

Figure 1 The refurbished IT user area.

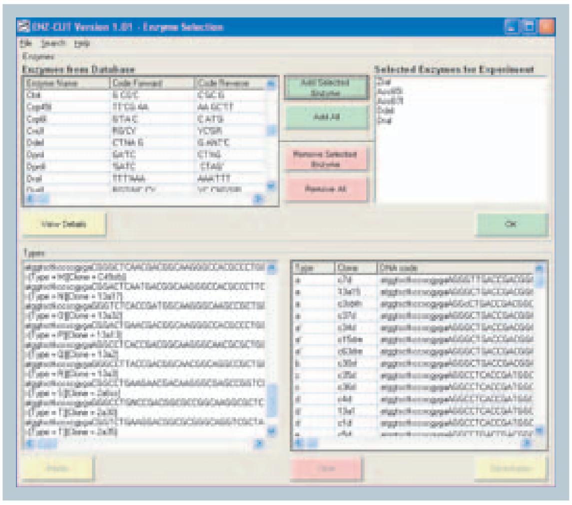

Figure 2 Enzyme cutting program for designing T-RFLP cocktails.

Finance and Human Resources Unit

N.G. Hattersley & A.Cartwright

The Finance and Human Resources Unit (FHR), comprises 16 staff covering accounts, contract management, administration, payroll and human resources.

The Institute employs approximately 350 staff (plus visiting workers and postgraduate students) and has income and expenditure of approximately £14 million with an additional capital grant this year of £2.51 million. The Unit is responsible not only for the financial regulation of the Institute's activities but also for providing training and a human resources service for all staff.

The HR section plays an important part in the development of staff and the provision of a positive working environment, providing support and guidance in all areas of staff welfare and ensuring that the policies and procedures in the BBSRC Staff Code are implemented effectively.

Working with the Senior Management Team, HR helps to develop a Manpower Plan that meets the needs of the SCRI Corporate Plan and ensures the effective recruitment of the staff required throughout the Institute. In 2002/03 (1st April 2002 – 31st March 2003) this included advertising 59 posts that attracted 873 applications from external and internal sources. HR is also responsible for the operation of effective induction and probation procedures to ensure that new staff become productive and effective members of the Institute quickly. On an ongoing basis HR continues to work with all managers to ensure that there is effective performance management throughout an individuals working career.

In addition HR is involved with internal staff committees in relation to the maintenance and development of the Institute's IIP status and the promotion and delivery of a wide range of training and development activities through the Institute Training Committee. These development activities include IT training, training in a range of management issues and appropriate scientific training to continually develop the skills of staff.

The accounts staff process over 17,000 purchase invoices per annum, 95% of which are paid within 30 days, utilising the BACS payment system to reduce the number of cheque payments. Over 1,100 sales invoices are raised in addition to the claims on grant aided projects. In addition to the 'core' research projects funded by the Scottish Executive Environment and Rural Affairs Department, additional income is sought from other external grant awarding bodies and from industry and the Institute carries out research on about 200 projects which are monitored and supported by the accounts team, particularly where the Institute acts as the co-ordinating partner for collaborative projects. The team also maintains over 2,700 items on its fixed asset register, ranging from personal computers to laboratory buildings.

The Institute is reliant on the funding from external bodies to maintain the resources and facilities of the Institute, therefore the development of staff, the monitoring of the finances and the control of the overhead expenditure is critical to the management of the Institute and its ability to produce world class science in an increasingly competitive research environment, both in terms of funding and output. This year has seen a reduction in research funding by commercial organisations and the role of budgeting and forecasting has become increasingly important to maintaining the financial integrity of the Institute, to ensure that it can respond to the changing demands of the sponsors and research programmes.

Estate, Glasshouse & Field Services Unit

P.A. Gill, G.R. Pitkin & E. Caldwell

Early in 2003, the Unit was renamed and reorganised to clarify its service provision to the science programmes within the institute.

David Petrie retired on 30 March 2003 after 34 years, having worked in both the Field and Glasshouse Sections on all aspects of soft fruit production. Latterly, he was heavily involved in weather observation at Mylnefield for both the Meteorological Office and local researchers.

Glasshouse Section The first phase of a new glasshouse complex and header house was opened in June 2003. It consists of large ($80m^2$), medium ($25m^2$) and small ($13m^2$) cubicles for general research use. This high quality 'Venlo' glasshouse has all plant growing conditions monitored and controlled by an environmental computer. Different temperate environments can be set up in each cubicle. Automatic irrigation and feeding of plants reduces the need for staff to access cubicles, minimising the spread of pests and diseases. Some cubicles have higher specifications for supplementary lighting and HEPA filters (14µ) on the fan ventilation inputs. This is especially important for growing barley for double haploidy, transformations, genomics and gene silencing research.

Close control of the growing environment is required for the screening of potato selections for leaf blight to ensure that spore germination and leaf penetration is achieved successfully. The glasshouse used for this work was upgraded with a new air conditioning system with humidity enhancement achieved through ultrasonic fogging.

The controlled environment facilities were updated by the overhaul of four rooms and the construction of a further three new rooms. Seven free-standing CE cabinets were also purchased during the year.

Contract work undertaken entirely by the glasshouse staff include germination tests of oilseed rape selections and the provision of game cover plants for exhibition by The Game Conservancy Trust.

Field Section Experimental land continues to be lost through road and building development. A further 22 hectares will be temporarily or permanently removed from the crop rotation system at the main Mylnefield/Bullionfield farm for the Science Park. Preparations for the infrastructure required the transfer of large numbers of experimental blackcurrant, raspberry and strawberry plants to a new site on the south of the farm.

The recommencement of SCRI's raspberry breeding was evident in the field by the construction of a one-hectare block of Spanish tunnels to assess new selections under commercial protective cropping regimes. This new venture required four field staff to attend a three-day course on the construction and operation of soft fruit tunnels.

The establishment of SCRI as a LEAF (Linking Environment And Farming) Innovation Centre to demonstrate new areas of research in sustainable agriculture has increased the ground area dedicated to 'green' activities. A range of minimum tillage treatments were applied to sowings of winter barley to assess their effects on crop performance and yield. Various projects under the Countryside Premium Scheme were continued and extended including tree

Interior of AO glasshouse.

Construction of Spanish tunnels

wind-breaks, species-rich grassland, beetle banks and mixed native hedgerows (hawthorn, blackthorn, elder, hazel, alder, holly and dog rose). The 10-hectare broad-leaf woodland, (oak, ash, birch, gean, hazel and rowan) under the Woodland Premium Scheme had extensive maintenance work carried out during the summer months to remedy weed and rabbit problems.

The provision of off-station field services has increased, especially for potato research and includes Ayr (blight trials), Balruddery (high-health seed production) and Glen Ogil (seed stock maintenance and selection).

Several contracts are undertaken by field staff. The genotype x environment interactions of American-switch, reed canary and elephant grasses for biomass accumulation continues to be assessed as part of a multi-site trial co-ordinated by Rothamsted Research. Another project examined the tensile strength and durability of a wide range of commercial and trial fleeces and their effects on potato yields.

Two new field committees were established - the Farm Strategy Group to co-ordinate the fundamental aspects and overall direction of farm activities and the Field Experiments Committee, to monitor the progress of each year's field trials.

Engineering and Maintenance Department

S. Petrie

The Engineering and Maintenance Unit within SCRI has a wide ranging remit regarding site services and facilities.

The Unit consists of fifteen engineering/technical posts along with six ancillary posts covering site security, stores and administration.

The Unit has a reputation for providing quality work and this has resulted in its role evolving into not only one of dealing with maintenance and repairs but also managing and carrying out refurbishment projects.

During 2002 refurbishment projects undertaken included complete refurbishment of fourteen laboratory areas plus refurbishment of fifteen offices. These projects were carried out mainly by our in-house staff who provided the electrical, heating, plumbing, data/telephony cabling, painting and joinery work. Where external contractors were required for other disciplines these resources were procured and thereafter managed by the Unit.

Upgrades or extensions were also made to the Institutes automatic fire detection, data/telephony cabling and glasshouse lighting control systems.

A new suite of three high quality plant growth walk-in rooms was installed while older rooms were refurbished.

Laboratory Equipment Services form a major part of the work of the Unit. Although as much as possible of this is carried out in-house the ever increasing sophistication of major pieces of equipment requires the services of external engineers. Again these resources are managed within the Unit which also negotiates service contract costs and conditions.

With good quality craft and engineering skills becoming increasingly difficult to find the importance of carrying out sizeable projects using the skills base available within the Unit have become ever more critical.

The Unit liases with the scientific staff to assess their requirements and thereafter effectively plans and manages the project through to completion.

The site is continuously becoming more sophisticated in terms of the systems required to ensure it operates effectively and safely.

The systems on site managed and maintained by the Unit include these for automatic fire detection, intruder alarm, closed circuit television, telephone exchange, door access, heating controls (including computerised glasshouse controls) and data networking throughout the site.

The Unit must also, through its farm workshop section, provide a repair and maintenance service to the Institutes estate unit in order to keep its large fleet of farm vehicles and machinery in good order.

Mylnefield Research Services Ltd.

N.W. Kerby & J.B. Snape

Introduction MRS, the wholly owned commercial subsidiary of the Scottish Crop Research Institute (SCRI), was established in 1989 to enhance competitiveness, understand and fulfil the needs of industry. The company has grown steadily.

The Mission Statement of MRS is:
To develop commercially the Scottish Crop Research Institute's scientific expertise, resources and intellectual property, and to improve the quality of services to achieve new standards of excellence.

MRS has an option on all intellectual property (IP) generated at SCRI and has access to a unique range of scientific expertise, laboratory, glasshouse and field facilities and germplasm collections. Particular areas of strength include plant pathology, molecular biology, plant genetics and breeding, soil and environmental sciences, in addition to chemistry, biomathematics and statistics. MRS uses a variety of routes to generate income from IP and expertise, including licensing, contract research and the sale of products and services. The profit made on these transactions is gifted back to SCRI either directly or indirectly through the Mylnefield Trust.

Strategy In April 2003 MRS, following consultation with SCRI senior management and its Board of Directors, launched a new Business Plan for the period 2003-2006. Over the next three years, MRS will make an essential contribution to the SCRI group in the following ways:

MRS will continue to make a significant contribution to the finances of SCRI. Gift aid will grow from £100k in 2003/2004 to £150k in 2005/2006. Turnover is predicted to drop to just below £1.4 million in 2003/2004 before recovering to £1.75 million in 2004/2005 and exceeding £2.0 million in 2005/2006.

The Lipid Analysis Unit will be spun-out in 2004/2005. The Lipid Analysis Unit will contribute financially to the SCRI Group by paying commercial rates for facilities and services and by the payment of dividends.

MRS will play a central role in the development of the Product Innovation Centre (PIC). The centre will coordinate research activities with commercial activities, including plant breeding, and will deliver the next generation products to meet end-user needs.

MRS will facilitate the development of new businesses based on SCRI IP and where possible locate them in the new SCRI Science Park. This will be achieved through business mentoring, accessing finance, interim management, incubating fledging companies and working alongside SCRI scientists and senior management to develop robust business plans.

Generate income for the group through the licensing of IP, especially plant variety rights, and collecting royalties. MRS will investigate the feasibility of licensing IP from other organisations on their behalf.

Generate income for the group through undertaking contract research at commercial rates with third parties utilising the resources and expertise at SCRI.

MRS in collaboration with SCRI and the PIC will intensify the marketing of SCRI expertise.

MRS will provide services to SCRI and other companies within the SCRI group. These services will include costing projects, IP management, drawing up and reviewing legal documents, contract negotiations, project management *etc.*

MRS will develop new products and services based on the resources and expertise available at SCRI.

In the short-term MRS faces a number of challenges relating to the profitability of the agricultural sector, public acceptance of GM products, difficulty in raising finance for "high tech" ventures and lack of investment in R&D. However, the medium to long-term future looks very promising. Several exciting concepts are being developed and include soil bioengineering, a UNIDO International Technology Centre for AgroIndustry, "SCRI Consultants" and Scottish Potato Technology Ltd.

MRS has patented several areas of technology on behalf of SCRI and also manages an extensive portfolio of plant variety rights on new cultivars, developed at SCRI.

Overall the strategy of MRS is to form appropriate partnerships and alliances to develop new competitive products and services and to capture value. The business of MRS is complex with a diverse customer base and is currently operating in a turbulent external environment with several competitors. In conclusion, MRS will: strengthen relationships with current customers by adding value to the services we offer; seek new customers and win contracts for research and product development; invest in people; enhance our working relationship with SCRI scientists.

Finances The income of MRS dropped from £1.94 million in 2001/2002 to £1.64 million in 2002/2003 largely due to the loss of one major contract. Despite this drop in turnover, charitable donations totalling £145k (£90k to SCRI and £55k to the Mylnefield Trust) were made in 2002/2003 as compared to a total of £158k in 2001/2002. Performance was better than had been predicted.

The Lipid Unit is ISO9001-accredited and is operating to GLP standards. Two successful training courses were held in 2002/2003 on lipid chemistry and analysis. The Lipid Analysis Unit turnover was in excess of £180K in 2002/2003.

Licensing and IP Asset Management MRS is responsible for ensuring that all varieties emanating from breeding programmes at SCRI are protected by plant variety rights, drawing up license agreements with third parties and collecting the royalties due. MRS investigates cases of illegal propagation and has successfully obtained financial recompense from growers in England, Sweden and the Netherlands.

A new blackberry variety named Loch Tay was launched in 2003. In addition two barley varieties and three potato varieties were entered into National List trials, and two potato varieties were grant European Plant Variety Rights (Lady Balfour, Eve Balfour and Thyme).

Raspberry Breeding A new seven-year raspberry breeding contract was signed in 2003. This programme is funded by the Horticulture Development Council, the Scottish Executive, the Scottish Society for Crop Research, and a consortium of all the major companies involved in the raspberry industry in the UK. This programme will lead to the release of several new raspberry varieties.

Scottish Potato Technology During 2003, MRS was instrumental in the incorporation of a new joint venture (JV) Scottish Potato Technology Ltd (SPT). SPT is a consortium of leading companies in the Scottish potato industry, which will commercialise collectively their extensive potato expertise, products and services in overseas markets with an initial emphasis on China. The JV partners are Cygnet PB, Greenvale AP Ltd, Higgins G&I Ltd, Mylnefield Holdings Ltd (on behalf of SCRI and MRS), FJ Pirie and Co Ltd, Reekie Manufacturing Ltd and Scottish Agricultural Science Agency.

The benefits to the SCRI Group include: developing a new market for our varieties, products and services; increasing royalty income in new, developing markets; improving networking both within and out with the UK; attracting contract research aimed at specific markets and environments

Human Resources MRS values highly the skills and experience of all its employees and recognises their contribution, together with that of SCRI scientific and administrative staff, to company performance. MRS is committed to investing in training to ensure that all employees not only perform effectively and efficiently, but also gain long-term satisfaction from their work. In addition to the Lipid Analysis Unit consultants (Prof Gunstone and Dr Christie) MRS retained the services of Mr George Mackay, MBE as a potato breeding consultant. Mr Kevin Wood was appointed in July as an Analytical Chemist within the Lipid Analysis Unit. Ms Karen Jackson was also appointed in July as a Graduate Technician to work on an externally funded contract.

Acknowledgements MRS gratefully acknowledges the support of all SCRI staff, for their significant contribution to the success of the company.

Mylnefield Trust and Mylnefield Holdings Mylnefield Holdings Ltd. (MHL) and the Mylnefield Trust were established in 2000 in order to give the SCRI Group the flexibility it requires to grow. Central to this growth is the creation of a number of spin-out companies that will be owned by MHL on behalf of the SCRI Group.

The Trustees are a group of individuals, including several members of the MRS Board of Directors and the SCRI Governing Body.

The Trust has charitable status and has as its prime objectives:

- to promote research and scientific work in the life, environmental and related sciences, in particular production of agricultural, horticultural and forestry crops, methods of limiting or eradicating pests and diseases, wood sciences and biomathematics, methods of increasing production or growth, improving cultivation and research into possible varieties.
- to promote the dissemination of such research

To date the Trust has funded a number of research and support activities atSCRI

Scottish Society for Crop Research

I. Kelly

The Scottish Society for Crop Research is a registered Friendly Society formed in 1981 by the amalgamation of the Scottish Society for Research in Plant Breeding and the Scottish Horticultural Research Association.

The Society provides a link between the Scottish Crop Research Institute and farmers, processors and other interested bodies.

The Society continued to support projects initiated in previous years such as "Malting Quality Analysis in Winter Barley Mixtures" with results of interest to the brewing industry. A contribution towards Mylnefield Research Services Ltd Raspberry Breeding Programme was repeated and the Society was pleased to see significant progress towards the signing of a major agreement to create a long term raspberry breeding programme. Grants enable Institute members of staff to attend conferences and seminars overseas to discuss their research, promote both the Institute and Society.

The Annual General Meeting of the Society was held on 29th May 2002. The AGM was attended by Prof David Hughes, of Imperial College, London who took as his topic "Improving the international competitiveness of the European Food Industry: the R&D Lifeline".

The Soft Fruit walk was re-instated this year and was held on 23rd July when the latest advanced selections of raspberries, strawberries and other soft fruits were displayed.

"Potatoes in Practice", the Society Potato event, in conjunction with the British Potato Council, the Scottish Agricultural College, and the Institute, was held in August and proved of interest to many members from all sections of the industry. There was a focus on the laboratory based aspects of the management of potatoes and their pests and diseases.

The Crop Sub-Committees including Cereals and Soft Fruit met throughout the year and informed the Management Committee of their approved projects for the coming season.

The Management Committee met twice during the year, in May and November, and was particularly concerned to progress the raspberry breeding programme and to develop a higher profile for the Society.

Society membership continues to decline due to retirement and contraction within the industry. In the meantime the Society is giving consideration to boosting both its membership and its activities.

The Management Committee welcomes suggestions for research topics, particularly focused on identifiable end user needs, and comment from members and others and urges them to contribute to the Society by joining one of the Crop Sub-Committees or indeed the Management Committee.

The Newsletter of the Society still languishes although it is hoped that it can make an appearance in the near future to include a set of articles on the Product Innovation Centre (PIC) at MRS/SCRI.

The Society now has a new Secretary, Mr Ian Kelly, and a new Treasurer, Dr Neil Hattersley, both based at SCRI. The Society records its appreciation of the contributions made by the previous Secretary/Treasurer Mr D L Hood.

Fruit walk July 2002

Health and Safety

M.J. De,Maine

There were no RIDDOR-reportable incidents during this year although there was one near-miss incident which could have had serious consequences. The hydraulic system of the wheels-free component of the garage vehicle lift was being bled when the bleed screw fell out, causing instant loss of pressure and collapse of the apparatus, narrowly missing the operator's hand. The provision of independent support for the component during bleeding has been written in to the risk assessment for this operation.

Working with extremely long and lightweight irrigation pipes beneath overhead high voltage power lines was recognized as a significant electrocution hazard to farm staff. Loading or unloading a pipe trailer is particularly hazardous as the trailer bed is raised several feet from the ground, so that the pipes are being manoeuvred that much closer to the cables. The pipes are so light, being made of highly conductive aluminium, that one man can hold a small-diameter nine-metre-long pipe in each hand. With the cables only 6.8 metres above the ground there was a danger that a person could absent-mindedly tip a pipe so that one end came close to the cables and caused an electric discharge resulting in death or injury. As a result of the risk assessment non-conductive plastic pipes were purchased for that part of the irrigation which was within a zone from the line of the cables out to six metres to one side (a roadway being on the other side).

In accordance with new Control of Substances Hazardous to Health regulations, wearers of respiratory protective equipment (RPE) at the Institute have undergone face-fit testing. The tests were carried out by a commercial company using a Portacount Fit Test meter. This counts the number of particles of a harmless test chemical inside and outside the mask that is being worn. The ratio between the counts outside and inside the mask must be above a threshold minimum before it can be concluded that a good fit has been achieved. The most efficient mask is identified for each operator. The test was combined with a training session on routine inspection and maintenance of RPE.

A noise survey of the joiner's workshop showed that noise levels varied from an L_{Aeq} of 73.8 (maximum dB(A) = 74.2) for the quietest machine in use (a Startrite bandsaw) to an L_{Aeq} of 100.4 (maximum dB(A) = 110.0) for the noisiest (a Dewalt cross-cut saw). Most of the equipment is used in very short bursts. Measurements were carried out on the machine which was used for the longest periods (about two hours at a time), namely the Wadkin Bursgreen table circular saw. This gave an $L_{EP,d}$ of 86.2 dB A. It was confirmed that the ear defenders used by the joiners, giving attenuation of 30.3dB, gave sufficient noise protection throughout the workshop.

The HSE carried out an audit of first-aid training which is provided by in-house trainers Heather Ross and James Anderson. The audit found that the training met the required standards in all respects.

A survey of traffic on the site has been carried out by a specialist consultant. His recommendations for changing the traffic flow in order to minimize vehicle-pedestrian interaction are in the process of being implemented.

Publications

Publications for the year 2002 are classified in the following manner:

J Papers describing original research in refereed journals.
R Critical reviews in journals, book chapters and reviews in books - providing each has been edited externally.
P Published proceedings of contributions to conferences or learned societies (including published abstracts).
T Technical reports, other publications.
O Popular articles, other publications.

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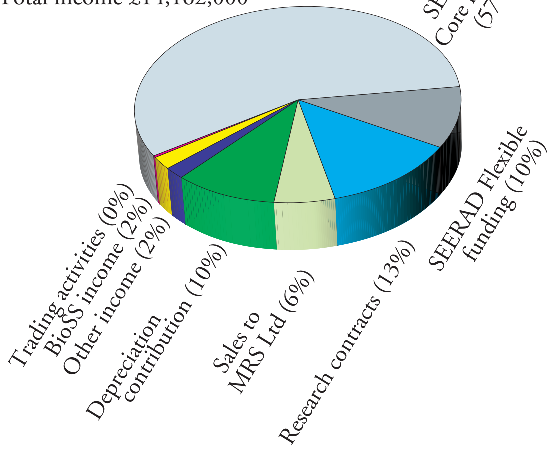
Summary of the Accounts

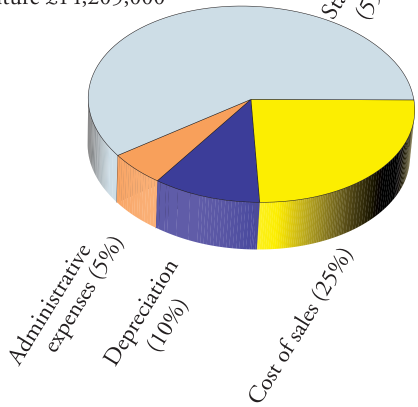
Income for the year ended 31 March 2002

Total income £14,162,000



Expenditure for the year ended 31 March 2002

Total expenditure £14,205,000



Balance sheet at 31 March 2002 **Total value £25,195,000**

Assets

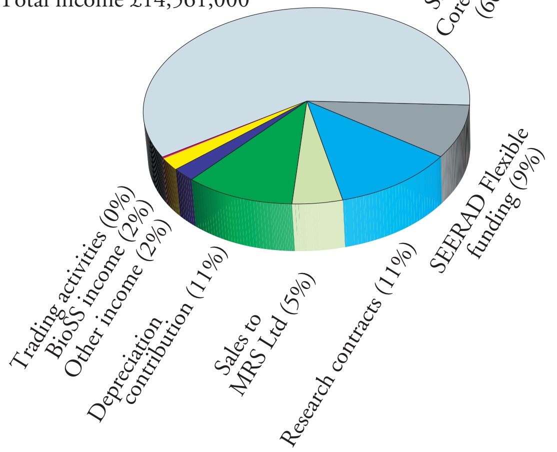
Fixed assets	92 %
Stocks	0 %
Debtors	8 %

Liabilities

Capital reserve	87 %
Income & expenditure account	3 %
Current liabilities	10 %

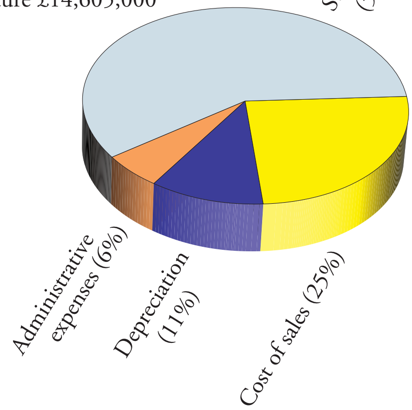
Income for the year ended 31 March 2003

Total income £14,561,000



Expenditure for the year ended 31 March 2003

Total expenditure £14,605,000



Balance sheet at 31 March 2003 **Total value £28,211,000**

Assets

Fixed assets	94 %
Stocks	0 %
Debtors	6 %

Liabilities

Capital reserve	86 %
Income & expenditure account	2 %
Current liabilities	12 %

Statement of health & safety policy

SCRI recognises and accepts its responsibilities for health, safety and welfare under the Health & Safety at Work Act 1974 and related legislation. The Institute has a senior member of staff responsible for health, safety and welfare management who reports to the Director. The health and safety team comprises a safety co-ordinator, first-aiders, fire officers, biological safety officers, hazardous waste managers, radiation protection officers and an occupational health adviser.

Training is made available for all staff and targeted groups of staff in order to maintain a high level of health and safety awareness. Regular inspections of the site and individual work areas are carried out by internal health and safety personnel and a 2-yearly external audit is carried out by a team of inspectors drawn from the other SABRI institutes and BBSRC.

Statement of quality policy

The Scottish Crop Research Institute is dedicated to achieving and maintaining the highest possible standards of quality in order to meet the requirements of its work programmes and the needs of its internal and external customers.

The aim of quality, in every instance, is meeting these requirements without defect, error or omission.

All employees must understand and be committed to their individual and collective responsibilities for quality.

To achieve these objectives, the management shall appraise the suitability of scientific and technical procedures, inspection and testing methods, and the training needs for existing and new employees. Through a process of continuous improvement in quality, SCRI will endeavour to create an environment of mutual benefit to our customers and ourselves.

Statement of environmental policy

The Institute will regularly assess the impact of its operations on the environment and take measures to reduce or eliminate negative effects. It aims to reduce waste of all types, increase the recycling of materials and have a benign or beneficial influence on the locality in which it is situated. Employees will be made aware of these aims and training will take place where necessary in order to achieve them. The Institute will work with statutory agencies in order to comply with legislation concerning the environment and related issues. It will carry out regular audits of its operations to ensure compliance with the policy.

Statement of data protection policy

The Scottish Crop Research Institute* will manage data in accordance with the requirements of the Data Protection Act (1998) and the BBSRC Staff Code.

It will retain only such personal data that are required for the conduct of staff administration. The data will be maintained securely to avoid unauthorised access and processing. Access to data is restricted to those who require it in order to efficiently administer the workforce. Data which are requested by a data subject will be confined to data which apply to that person. Data not referring to the data subject will be withheld or made unreadable.

Processing of personal data will be restricted to that required for the administration of the SCRI workforce

There will be periodic reviews of personal data and those which are obsolete or no longer necessary for staff administration will be destroyed. The review will take place annually (usually in March).

* For the purposes of data protection administration The Scottish CropResearch Institute includes MRS and BIOSS.

The Governing Body

Chairman: J.E.Godfrey, B.Sc., F.R.Ag.S., gained his degree in agriculture from the University of Reading. He is a Director of family farming companies in Lincolnshire and Yorkshire. He is Chairman of Willisham Group plc, and is a member or adviser to numerous committees including the Royal Agricultural Society of England. He is a Trustee of the International Potato Center (CIP) in Peru and a Director of World Potato Congress Inc. He was appointed to the Governing Body of SCRI in 1991, became Vice Chairman in 1997 and Chairman in 1999.

E. Angus, MBE, M.Sc., Fio.D., has been actively involved in the start-up of several knowledge economy companies since retiring from Napier University in 1999, where he held the post of Business Director for the University and Managing Director of Napier University Ventures Limited. His degree in corporate leadership was gained after studying business incubation systems and processes in the US, UK, the Continent and Scandinavia. His strategic management experience at Board level in food, textiles and distribution companies, span a period of 25 years and he was awarded the honour of an MBE for his contribution to exporting in 1977. He was appointed to the Governing Body of SCRI in 2000.

Professor J.J.F. Belch, M.B., Ch.B., F.R.C.P., M.D., is Professor of Vascular Medicine at the University of Dundee, where she is interested in the causes, manifestations and treatment of disease of the blood vessels and circulation. Additionally she is a member of the Medical Research Council Advisory Board, a member of the Scottish Office Acute Services Review Sub-Committe on Peripheral Arterial Disease, and UK Chairman of the Forum on Angiology. Her interests in terms of crop research relate to the antioxidant content of food, specific fatty acid types within oils, and the relationships of these to vascular disease. She was appointed to the Governing Body of SCRI in 1998.

Professor R.J. Cogdell, B.Sc., Ph.D., F.R.S.E., was awarded his two degrees by Bristol University, and completed his post-doctoral research in the USA. He joined the Botany Department of Glasgow University (now the Institute of Biomedical and Life Sciences) in 1975, and currently holds the Hooker Chair of Botany there. He was awarded a Humbolt Research Prize in 1995. He was appointed to the Governing Body of SCRI in 1997, and was recently re-appointed. He is a member of the Chairman's Committee, and Chairs the Science Sub-Committee. He is a Director of MRS and a Trustee of the new Mylnefield Trust.

Dr K. Dawson, B.Sc., Ph.D., D.I.C.P., is Technical Director of CSC CropCare, the largest privately owned crop consultancy service in the North of the UK. He trained as an agricultural and environmental scientist and was awarded his degrees by the University of Newcastle-Upon-Tyne and the University of Reading. He joined the Scottish Agricultural College in 1982 and, after a spell as Northern Technical Advisory Manager for BASF(UK) Ltd, formed CSC CropCare in 1987. He is an elected director of BASIS(UK) Ltd and a member of the Government's Pesticide Forum. He also has been closely associated with the Scottish Natural Heritage TIBRE programme, utilising new technology for agronomic and environmental benefit. His main interests are in crop protection and Integrated Farming Management. He was appointed to the Governing Body of SCRI in 2000.

Dr M. Eddie, B.Agr., Ph.D., gained both his degrees from The Queen's University, Belfast. After employment as a research scientist by the Ministry of Agriculture, Northern Ireland for 4 years, he joined Unilever plc where he spent 25 years mainly in their agribusiness operations, eventually becoming Chairman, in sequence, of two agribusiness companies. The first was based in Scotland and the second in Malaysia. After retirement from Unilever in 1999, he was appointed to the Governing Body of SCRI in March 2000.

Professor M.J. Emes, B.Sc., Ph.D., is Director of the Research and Graduate School in the Faculty of Biological Sciences, University of Manchester, where he is responsible for over 120 academic staff and the training of 400 postgraduate students. His own research activities are focused on understanding the control of plant metabolism, particularly mechanisms of regulating starch synthesis in cereals. He has extensive experience of BBSRC grants committees and is a member of the Governing Council of the John Innes Centre. He is also an editor of the Journal of Experimental Botany. He was appointed to the Governing Body of SCRI in 2000.

Professor J. Evans, OBE, B.Sc., Ph.D., D.Sc., F.I.C.For., is Professor in Tropical Forestry (part time) at Imperial College, London, and was formerly Chief Research Officer (S) with the UK Forestry Commission from 1989 to 1997. He is Chairman of the Commonwealth Forestry Association and is Chair of DfID's Programme Advisory Committee for Forestry Research. Professor Evans also holds an honorary Chair of Forestry at the University of North Wales, Bangor. He is the author of eight technical books, including the newly published Forests Handbook and the standard text on tropical forest plantations. Professor Evans owns and manages his own small woodland. He was appointed to the Governing Body of SCRI in 1998.

Wendy Goldstraw, B.Sc., P.G.Dip.B.A., M.C.I.P.D., gained her degrees from the University of Edinburgh, before joining the Post Office as a management trainee. After a number of roles in human resources and line management, she was latterly General Manager for Post Office Counters Ltd for Scotland and Northern Ireland, with responsibility for 2800 Post Offices. She was an executive member of both the Scottish and Northern Ireland Post Office Boards, and served as a Director of Edinburgh Chamber of Commerce and also on the Scottish Committee of the Institute of Directors. She has been a member of the Accounts Commission for Scotland since 1994. She was appointed to the Governing Body of SCRI in 2000.

K. Hopkins, F.C.A., joined Reeves & Neylan, Chartered Accountants, in Canterbury, Kent, in 1971, from a farming background. He moved to open the Scottish Practice in 1978 and was appointed a partner in 1981. 'The Scottish Partnership' (a separate business since April 1996) acts for over 500 farmers in Scotland, and specialises in the establishment of farmer-led agricultural cooperatives. His firm now has three offices, Forfar, Perth and Dundee, and employs over 60 staff. Mr Hopkins specialises in capital taxes, agricultural law and cooperatives, development and expansion of business, writes for the agricultural press, and lectures throughout Scotland. He is Treasurer for District 1010 of Rotary, a member of the Institute of Directors, and Chairman of the charity Childlink Scotland. He was appointed to the Governing Body of SCRI in 1997.

Professor B. King, M.Sc., Ph.D., F.I.W.Sc., C.Biol., F.I.Biol., is Principal and Vice-Chancellor, University of Abertay Dundee, having joined it in 1992 from the Robert Gordon University, Aberdeen, where he was Assistant Principal and Dean of the Faculty of Health and Food. He is a Non-Executive Trustee of Tayside Primary Care NHS Trust, Board Member of Scottish Enterprise Tayside, Governor of the Unicorn Preservation Society, and a member of the Institute for Learning and Teaching in Higher Education. He is a member of the International Research Group on Wood Preservation and of the Biodeterioration and British Mycological Societies. He was appointed to the Governing Body of SCRI in 1998.

I. McLaren, S.D.A., is a partner in a family owned farming business, specialising in potato and cereal production. He is also a partner in a retail dairy business, a garage business, and a visitors' centre. He is Chairman of a leisure complex, the Dewar's Centre in Perth, and a member of the Perth & Kinross Agricultural Forum, and was a member of the Home-Grown Cereals Authority from 1988 to 1997. He was appointed to the Governing Body of SCRI in 2000.

Emeritus Professor Sir John S. Marsh, C.B.E., M.A., P.G. Dip. Ag. Econ., F.R.A.S.E., F.R.Ag.S., C.Biol., F.I.Biol., was Professor of Agricultural Economics, University of Aberdeen, from 1977-1984, then Professor of Agricultural Economics, University of Reading from 1984-1997. He is a Former Director of the Centre of Agricultural Strategy and Chairman of the Agricultural Wages Board, and is currently Chairman of RURAL Council, Governor of the Royal Agricultural College, and Member of the Agriculture, Horticulture and Forestry Foresight Panel. He was made a Knight Bachelor in the Queen's Birthday Honours List in 1999 for his wide-ranging contributions to agriculture and agricultural research. He was appointed to the Governing Body of SCRI in 1998.

Professor A.R. Slabas, B.Sc., D.Phil., is Head of Plant Molecular Biology Research in the Department of Biological Sciences, University of Durham, where he leads a team involved in various aspects of lipid metabolism ranging from novel gene identification to structural studies. His more recent interests are in proteomics and the plant cell wall. He has extensive collaboration with Industry, including Biogemma, Zeneca, Linnaeus and Unilever. He has served as a panel member of the UK Technology Foresight Programme 'Crops for Food and Industrial Use'; the Eukaryotic Cell Link Management Committee; and the BBSRC Inovative Manufacturing Committee. He joined the Governing Body in 1995.

P. Whitworth retired from United Biscuits plc as Technical Director, Snacks. During his 38 years with the company, he was associated with all aspects of the development and production of biscuits, potato crisps and savoury snacks. He joined the board of the European Snacks Association (ESA) in 1988, and served as President of the Association from 1994 to 1996. He was a founder Director of ECSA Research Ltd (ERL), which through an ECLAIR funded project sought to improve the quality of crisping potatoes using genetic manipulation. A major part of this work has been carried out at SCRI. Having retired from the board of ERL, he was appointed to the Governing Body of SCRI in 1997 and is now a member of the Chairman's Committee and a Director of MRS.

Staff list as at 31 March 2003

Director	Professor J.R. Hillman, B.Sc., PhD., D.Sc., F.I.S., C.Biol., F.I.Biol., F.C.M.I., F.I.Hort., F.R.S.A., F.R.S.E.[2,3,4,9]	Band 1
Deputy Director	Professor W. Powell, B.Sc., M.Sc., Ph.D., D.Sc.[5,6,7,9,18]	Band 2
Company Secretary	D. Watt, L.L.B., C.A.	Band 3
Assistant to Director	T.J.W. Alphey, B.Sc., Ph.D., C.Biol., M.I.Biol.	Band 4

Theme 1 – Mechanisms and Processes

Theme Co-Ordinator: G.C. Machray, B.Sc., Ph.D.[1,9] Band 3

Programme 1 – Gene Expression (GE)

Programme Leader: J.W.S. Brown, B.Sc., Ph.D.[9]	Band 3 (IMP)
Associate Programme Leader:	
S.A. MacFarlane B.Sc., Ph.D.	Band 4
G.C. Machray, B.Sc., Ph.D.[1]	Band 3
P.F. Palukaitis, B.Sc., Ph.D.[6,12,20]	Band 3
H Barker, B.Sc., Ph.D.[9]	Band 4
C.G. Simpson, B.Sc., Ph.D.	Band 4 (Prom. Jul 02)
M. Taliansky, Ph.D, DSc.[21]	Band 4
T Canto, B.Sc., Ph.D.	Band 5 (SPD)(Prom. Jul 02)
P. Hedley, B.Sc., Ph.D.	Band 5 (SPD)
B. Reavy, B.Sc., Ph.D.	Band 5 (SPD)
S.Millam, B.Sc., Ph.D.[9]	Band 5
G Thow, B.Sc., Ph.D.	Band 6 (PD)
M.M. Swanson, B.Sc., Ph.D.	Band 6
G. Clark, H.N.C., B.Sc.	Band 7
S.M.S. Dawson, H.C.	Band 7 (P/T)
B. Harrower, H.N.D., B.Sc., M.Sc.	Band 7
K.D. McGeachy, H.N.C.	Band 7 (P/T)
J. Middlefell-Williams, H.N.C.	Band 7
D. Davidson	Band 8 (P/T)
G.L. Fraser	Band 8 (P/T)
J.D. Fuller	Band 8
J. Morris, H.N.D., B.Sc.	Band 8
J. Donnelly	Band 9
DNA Sequencing / Genotyping Facility	
C. Booth, B.Sc.	Band 7
Media Kitchen	
W. Ridley	Band 7
E. Warden, O.N.C.	Band 9
W. Burry	Band 11 (HELM)
M Burton	Band 11
J. McMillan	Band 11 (P/T) (HELM)
Administrators	
A. Addison	Band 7
F. Watt	-
Leverhulme	
S.H. Kim, B.Sc., Ph.D.	Band 6 (PD)
EU	
B. Obert, M.Sc., Ph.D.	Band 6 (PD)
G. McKenzie, H.N.D., B.Sc.	Band 8

Programme 2 – Cell-to-Cell Communications (CCC)

Programme Leader: K.J. Oparka, B.Sc., Ph.D.[6]	Band 2 (IMP)(Prom. Jul 02)
Associate Programme Leader:	
A.G. Roberts, B.Sc., Ph.D.[9]	Band 6 (PD)
P.Boevink, B.Sc., Ph.D.	Band 5 (SPD)
S.N. Chapman, B.Sc., Ph.D.	Band 5 (SPD)
C. Lacomme, B.Sc., Ph.D.	Band 5 (SPD)
K.M. Wright, M.A., Ph.D.	Band 5 (SPD)(Prom. Jul 02)
G.H. Duncan, H.N.C.	Band 5
T.L. Gillespie, B.Sc., Ph.D.	Band 6 (PD)
F. Carr, O.N.C., H.N.D.	Band 8
K. Hrubikova, M.Sc., Ph.D.	Band 8
Administrator	
F. Watt	-
SEERAD FF	
K.M. Nurkiyanova, M.Sc., Ph.D.	Band 6 (PD)
J. Shaw, B.Sc.	Band 7

Programme 3 – Plant-Pathogen Interactions (PPI)

Programme Leader: L. Torrance, B.Sc., Ph.D.[9]	Band 4
Associate Programme Leader:	
P.R.J. Birch, B.Sc., Ph.D.	Band 5 (SPD)
V. Blok, B.Sc., M.Sc., Ph.D.	Band 4 (Prom. Jul 02)
A. Kumar, B.Sc., Ph.D.	Band 4 (Prom. Jul 02)
G.D. Lyon, B.Sc., M.Sc., Ph.D., D.I.C.[9]	Band 4
M.S. Phillips, B.Sc.[9]	Band 4
I.K. Toth, B.Sc., Ph.D.[14]	Band 4 (Prom. Jul 02)
B. Williamson, B.Sc., M.Sc., Ph.D., D.Sc.[9]	Band 4
J.T. Jones, B.Sc., Ph.D.[9]	Band 5 (SPD)
A. Ziegler, B.Sc., Ph.D.	Band 5 (SPD)
L.J. Hyman, B.A., M.Sc.	Band 6
G.H. Cowan, H.N.C., M.Sc.	Band 7
J. Heilbronn, H.N.C., B.Sc.	Band 7
A. Smith, B.Sc.	Band 7 (P/T)
A.M. Holt	Band 8 (P/T)
A.J. Paterson, H.N.D.	Band 8 (P/T)
Administrators	
M. Murray	Band 8
F. Watt	-
SEERAD Fellowship	
S. Whisson, B.Sc., Ph.D.	Band 5 (SPD)
SEERAD FF	
M. Armstrong, B.Sc., Ph.D.	Band 6 (PD)
A. Avrova, B.Sc., PhD.	Band 6 (PD)
K. Bell, B.Sc., Ph.D.	Band 6 (PD)
L. Castelli, B.Sc., M.Sc.	Band 7
EU	
B. Banks, B.Sc., Ph.D.	Band 6 (PD)
J. Wishart, B.Sc., Ph.D.	Band 6 (PD)
Q. Chen, B.Sc., M.Sc., Ph.D.	Band 6
A.M. Holt,	Band 7 (P/T)
J.A. Stewart, H.N.D., B.Sc.	Band 8

[1] Visiting Professor in the University of Strathclyde
[2] Visiting Professor in the University of Dundee
[3] Visiting Professor in the University of Edinburgh
[4] Visiting Professor in the University of Glasgow
[5] Honorary Senior Lecturer in the University of St. Andrews
[6] Honorary Senior Lecturer in the University of Dundee
[7] Honorary Professor, Oregon State University
[8] Professor, Universities of Cordoba and Malaga
[9] Honorary Lecturer in the University of Dundee
[10] Honorary Lecturer in the University of Glasgow
[11] Associate Professor, University of Parma
[12] Adjunct Professor, Cornell University
[13] Visiting Professor, University of Zhejiang, China
[14] Honorary Lecturer in the University of Aberdeen
[15] Honorary Research Fellow in the University of Dundee
[16] Honorary Fellow in the University of Edinburgh
[17] Honorary Lecturer in the University of Strathclyde
[18] Honorary Professor, Heriot-Watt University, Edinburgh
[19] Visiting Professor, University of Naples, Italy
[20] Honorary Professor, Seoul Women's University
[21] Adjunct Professor, Moscow State University

Theme 2 – Genes to Products

Theme Co-Ordinator: H.V. Davies, B.Sc., Ph.D., C.Biol., F.I.Biol[6,8] Band 3

Programme 4 – Quality, Health and Nutrition (QHN)

Programme Leader:	
R. Viola, B.Sc., Ph.D.[9]	Band 4
Associate Programme Leader:	
M.A. Taylor, B.Sc., Ph.D.[9,10]	Band 4
H.V. Davies, B.Sc., Ph.D., C.Biol., F.I.Biol[6,8]	Band 3
B.A. Goodman, B.Sc., Ph.D., C.Chem., F.R.S.C.	Band 4
D.W. Griffiths, M.A., Ph.D., C.Chem., M.R.S.C.	Band 4
G.J. McDougall, B.Sc., Ph.D.	Band 4
D. Stewart, B.Sc., Ph.D.	Band 4
N. Deighton, B.Sc., Ph.D., C.Chem., M.R.S.C.	Band 5 (SPD)
G. Dobson, B.Sc., Ph.D.	Band 5 (SPD)
S.M. Glidewell, M.A., Ms.C., Ph.D.	Band 5 (SPD)
T. Shepherd, B.Sc., Ph.D.	Band 5 (SPD)(Prom. Jul 02)
H.A. Ross, H.N.C., Ph.D., C.Biol., M.I.Biol.	Band 6 (PD)
L.V.T. Shepherd, B.Sc., M.Sc., Ph.D.	Band 6 (PD)
L. Ducreux, B.Sc., Ph.D.	Band 7
R.A. Marshall, B.Sc., Ph.D.	Band 7
W.L. Morris, B.Sc., M.Sc	Band 7
J.A. Sungurtas, H.N.D.	Band 7
S.R. Verrall, H.N.C.	Band 7
F. Falconer, H.N.C.	Band 8
D. McRae, O.N.C.	Band 8
J.F. Wilkie,	Band 10
R. Hutchison,	Band 11 (P/T) (HELM)
Administrator	
E.L. Stewart	Band 7
SEERAD FF	
A. Blake, B.Sc.	Band 7
P.L. Smith, B.Sc.	Band 9 (P/T)
Hortlink	
R.D. Hancock, B.Sc., Ph.D.	Band 6 (PD)
C.S. Jorna	Band 8
DEFRA	
S. Haupt, Dip.Biol.	Band 6 (PD)
P.G. Walker, H.N.D.	Band 10
FSA	
S.Conner, B.Sc., M.Sc., C.Chem., M.R.S.C.	Band 8
P. Neave	Band 10
EU	
O. Faivre-Rampant, B.Sc., Ph.D.	Band 6 (PD)
K. Harper, B.Sc., Ph.D.	Band 6 (PD) (P/T)
P.M. Dobson,	Band 10
J. Oparka, B.Sc.	Band 11 (P/T)
Proof of Concept	
G.D. Hunter, B.Sc., Ph.D.	Band 6 (PD)
P. Proudlock, B.Sc.	Band 7

Programme 5 – Genome Dynamics (GD)

Programme Leader:	
R. Waugh, B.Sc., Ph.D.[9]	Band 3 (IMP)
Associate Programme Leader:	
J.E. Bradshaw, M.A., M.Sc., Ph.D.[9]	Band 4
W. Powell, B.Sc., M.Sc., Ph.D., D.Sc.[5,6,7,9,20]	Band 2
R.M. Brennan, B.Sc., Ph.D.	Band 4
G. Bryan, B.Sc., Ph.D.	Band 4 (Prom. Jul 02)
M.F.B. Dale, B.Sc., Ph.D.[9]	Band 4
R.P. Ellis, B.Sc., Ph.D.[9]	Band 4
B.P. Forster, B.Sc., Ph.D.[9]	Band 4
J. Graham, B.Sc., Ph.D.	Band 4
W.T.B. Thomas, B.Sc., Ph.D.	Band 4
G. Ramsay, B.Sc., Ph.D.	Band 5 (SPD)
J. Russell, B.Sc., Ph.D.	Band 5 (SPD)
J.S. Swanston, B.Sc., Ph.D., C.Biol., M.I.Biol.	Band 5 (SPD)
I. Hein, M.Sc., Ph.D.	Band 6 (PD)
S.J. Rae, B.Sc., M.Sc., Ph.D.	Band 6 (PD)
L. Ramsay, B.Sc., Ph.D.	Band 6 (PD)
D. Caldwell, B.A.	Band 6
J. Lyon	Band 7
N. McCallum, B.Sc.	Band 7
K. McLean, B.Sc.	Band 7
J. McNicoll, H.N.C., B.Sc.	Band 7
M. Macaulay, H.N.C., B.Sc.	Band 7
G.E.L. Swan	Band 7
D. Todd, B.Sc., M.Sc.	Band 7
R.N. Wilson, H.N.C.	Band 7
G.R. Young, H.N.C.	Band 7
N.Bonar, H.N.C.	Band 8
A. Booth, H.N.C.	Band 8
R. Keith	Band 8
P.E. Lawrence	Band 8
H.A. Mathews	Band 8
K. Smith, Dip.H.E.	Band 8
J. Brown	Band 9
A.M.S. McInroy	Band 9
M. Myles, O.N.C.	Band 9
G. Wilde	Band 9
Administrator	
S. Forsyth	Band 8
SEERAD FF	
A. Druka, M.Sc., Ph.D.	Band 5 (SPD)
A. Purvis, B.Sc., Ph.D.	Band 6 (PD)
M. Woodhead, B.Sc., Ph.D.	Band 6 (PD)
H. Liu, M.Sc.	Band 7
S.L. Williamson, B.Sc.	Band 7
S.F. Blackie, B.Sc.	Band 8
J.N. Anderson, B.Sc.	Band 9
BBSRC	
S. Mudie, B.Sc.	Band 8
FSA	
A. Ibrahim, B.Sc., Ph.D	Band 5 (SPD)
Leverhulme	
A. Masoudi-Nejad, B.Sc., Ph.D.	Band 6 (PD)
Glaxo SmithKline	
L. Jorgensen, H.N.D.	Band 8

Theme 3 – Management of Genes and Organisms in the Environment

Theme Co-Ordinator – G.R. Squire, B.A., Ph.D. Band 3

Programme 6 – Ecosystem Management and Biotechnology (EMB)

Programme Leader: G.R. Squire, B.A., Ph.D.	Band 3
Associate Programme Leader:	
G.S. Begg, B.Sc., Ph.D.	Band 6 (PD)
C. Hawes, B.Sc., Ph.D.	Band 6 (PD)
P.P.M. Iannetta, B.Sc., Ph.D.	Band 6 (PD)
M. Young, H.N.D., M.Sc., Pg.Dip.I.T.	Band 6 (PD)
G.M. Wright, H.N.C.	Band 7
Administrator	
S. Inglis	Band 7
DEFRA	
D. Cullen, B.Sc., Ph.D.	Band 6 (PD)
T. Dixon, B.Sc., Ph.D.	Band 7
J. McCluskey, B.Sc.	Band 8
F. McCowan, B.Sc.	Band 8
L.K. Brown, B.Sc.	Band 9 (P/T)
L. Ford, B.A.	Band 9
G. Robertson	Band 9
DETR	
G. Banks, B.Sc., M.Sc.	Band 7
A. Parish, B.Sc.	Band 7

Programme 7 – Plant-Soil Interface (PSI)

Programme Leader: B. McKenzie, B.Sc., Ph.D.	Band 4
Associate Programme Leader:	
B.S. Griffiths, B.Sc., Ph.D.[9]	Band 4
A.G. Bengough, B.Sc., Ph.D.[9]	Band 4
B.Boag, B.Sc., Ph.D.	Band 4
R.E. Wheatley, B.Sc., Ph.D.	Band 4
T.J. Daniell, B.Sc., Ph.D.[9]	Band 5 (SPD)
P.D. Hallett, B.Sc., Ph.D.	Band 5 (SPD)(Prom. Jul 01)
C.M. Scrimgeour, B.Sc., Ph.D.[9]	Band 5 (SPD)
T. Valentine, B.Sc., Ph.D.	Band 6 (PD)D.C.
Gordon, H.N.C.	Band 6
W.M. Stein, H.N.C., B.Sc.	Band 6
K. Binnie, B.Sc.	Band 8
J. Davidson, B.Sc.	Band 7 (P/T)
S. Mitchell, B.Sc.	Band 7
Administrator	
S. Inglis	Band 7
SEERAD FF	
L. Deeks, B.Sc., Ph.D.	Band 6 (PD)
N. Nunan, B.Sc., M.Sc., Ph.D.	Band 6 (PD)
H.L. Kuan, B.Sc., M.Sc.	Band 7
J.N. Squires, B.Sc., Ph.D.	Band 7
Y. Pitkin, B.Tec., H.N.D.	Band 8 (P/T)
BBSRC	
S. McDermott, B.Sc., M.Sc. Ph.D.	Band 6 (PD)
V. Stubbs, B.Sc., Ph.D.	Band 6 (PD)
EU	
S. Caul, H.N.C.	Band 6
C. Fernie, B.Sc.	Band 6 (P/T)
J.A. Thompson, B.Sc.	Band 8

Programme 8 – Host-Parasite Co-Evolution (HPCE)

Programme Leader: J.M. Duncan, B.Sc., Ph.D.[6]	Band 3
Associate Programme Leader:	
A.C. Newton, B.Sc., Ph.D.	Band 4
A.T. Jones, B.Sc., Ph.D.[6]	Band 3 (IMP)
A.N.E. Birch, B.Sc., Ph.D., C.Biol., M.I.Biol., F.R.E.S.	Band 4
D.J. Robinson, M.A., Ph.D.[9,13]	Band 4
B. Fenton, B.Sc., Ph.D., C.Biol., M.I.Biol.[9]	Band 5 (SPD)
D.E.L. Cooke, B.Sc., Ph.D.	Band 5 (SPD)
A.K. Lees, B.Sc., Ph.D.	Band 5 (SPD)
S.C. Gordon, H.N.C.9	Band 5
R. Neilson, H.N.C., M.Sc., Ph.D.	Band 6 (PD)
G.L. Malloch, D.C.R., B.Sc., Ph.D.	Band 6
R.M. Solomon-Blackburn, B.A., M.Sc.	Band 6
W.J. McGavin, B.Sc.	Band 7
A. Dolan, H.N.C.	Band 7 (P/T)
N.A. Williams, H.N.C.	Band 7
D.C. Guy, H.N.D.	Band 7
S.S. Lamond	Band 8
L. Sullivan, B.Sc.	Band 8
Administrators	
M. Murray	Band 8
F. Watt	-
SEERAD FF	
M.R. MacLeod, B.Sc., Ph.D.	Band 6 (PD)
V. Young, B.Sc.	Band 7
J.A. Sinclair, M.Sc.	Band 8
SEERAD / BPC	
P. Van de Graaf, B.Sc., M.Sc., Ph.D.	Band 6 (PD)
BPC	
M. Elliott, B.Sc.	Band 7

Programme 9 – Computational Biology (CB)

Programme Leader: D.F. Marshall, B.Sc., Ph.D.	Band 4
Associate Programme Leader:	
B. Marshall, B.Sc., A.R.C.S. Ph.D.[16]	Band 4
J. Liu, B.Sc., M.Sc., Ph.D.	Band 5 (SPD)
L. Cardle, B.Sc., Ph.D.	Band 6 (PD)
P.D. Shaw, M.Sc.	Band 7
SEERAD FF	
G.A. Jamieson, B.Sc., Ph.D., PG.Dip.	Band 6 (PD)
External Funding	
I. Druka, B.Sc., Ph.D.	Band 6

Division of Finance and Administration

Head: J.D. Watt, L.L.B., C.A. Band 3

Unit of Finance and Human Resources (FHR)

Financial Controller:
N.G. Hattersley, B.Sc., Ph.D., A.C.M.A. Band 4
Assistant Secretary:
D.L. Hood, B.Admin., Dip.Ed., L.T.I., A.I.I.M. Band 6
Human Resources Manager:
A.J. Cartwright, B.A., D.M.S., M.C.I.P.D. Band 5
Director's Secretary: A. Pack Band 7

D.L. Beharrie, Dip.Ed.	Band 8
S. Bell	Band 8
R.G. Davidson,	Band 8
P. Duncan	Band 8
L. Ellis, H.N.C.	Band 8
K.L. Grant, B.A.	Band 8
B.V. Gunn	Band 8
S.M. Phillip, B.A.	Band 8
J.Keith	Band 9

Unit of Scientific Liaison and Information Services (SLIS)

Head: I. Kelly, B.Sc., Dip. T.P. M.R.T.P.I.[9] Band 4
Deputy Head: S.E. Stephens, B.Sc., M.A., A.L.A. Band 5

T.G. Geoghegan, A.B.I.P.P., A.M.P.A.	Band 5
K.S. Athwal, B.Sc.	Band 6
I.R. Pitkethly, H.N.D.	Band 6
U.M. McKean, M.A., Dip.Lib.	Band 7
S.F. Malecki, A.B.I.P.P.	Band 7
S.J. Neilson, Dip.Biol.Sci., Dip.Poll.Con., B.Sc.	Band 7
L. Fiddes, H.N.C.	Band 9
S.K. Thomson, H.N.D., B.A.	Band 9

Safety Coordinator: M.J. De,Maine, B.Sc., M.Phil. Band 5

Unit of Information Technology (IT)

Head: B. Marshall, B.Sc., A.R.C.S., Ph.D.[16] Band 4
Operations Manager: S. Clark, H.N.C., M.Sc. Band 5

P. Smith, B.Sc.	Band 6
T. Spiers	Band 6
L.H. Davidson, B.A.	Band 7
L.A. McGregor, B.Sc.	Band 8

Unit of Engineering and Maintenance (EM)

Head: S. Petrie, B.Sc. Band 4

D. Gray, H.N.C.	Band 6
A. Low	Band 6
I.C. McNaughton, H.N.C.	Band 6
K.A. Henry	Band 8
R.D. McLean	Band 8
G.C. Roberts	Band 8
B. Ward	Band 8
R. White	Band 8
J. Anderson	Band 9
D. Byrne	Band 9
R. Craik	Band 9
J.Flight	Band 9
A.G. Fox	Band 9
E. Lawrence	Band 9
C.G. Milne	Band 9
D.L.K. Robertson	Band 9
W. Scott	Band 9
C. Conejo	Band 10
D.J. Redford	Band 10
J. Rowe	Band 10
B. Semple	Band 10
M.J. Soutar	Band 10
J. Lawrence	Band 11 (P/T)
E. Millar	Band11 (P/T)
F. Mitchell	Band 11 (P/T)
W. Pollock	Band 11 (P/T)
G. Pugh	Band 11 (P/T)
V. Tait	Band 11 (P/T)

Administrator
W.A. Patterson, H.N.D. Band 8

Estate, Glasshouse and Field Services (EGFS)

Head: G. Wood, B.Sc., Ph.D., F.E.T.C. Band 4
Glasshouse Manager: P.A. Gill, H.N.D., N.E.B.O.S.H. Band 5

E. Caldwell	Band 6
G.R. Pitkin, H.N.D.	Band 6
J.R.K. Bennett	Band 7
W.D.J. Jack, B.Sc.	Band 7
D.S. Petrie	Band 7
A.W. Mills	Band 8
R. Ogg	Band 8
G Pugh	Band 8
A.M. Thain, H.N.C.	Band 8
J.T. Bennett	Band 9
A. Dobson, H.N.C., H.N.D.	Band 9
B. Fleming	Band 9
D.I. Matthew, B.Sc.	Band 9
J.K. Wilde	Band 9
P. Baird	Band 10
C.A. Cuthill, N.C.	Band 10
I. Fleming	Band 10
A.C. Fuller	Band 10
M. Grassie, H.N.C., B.Ed.	Band 10
D.J. Harkins	Band 10
P. Heffell, O.N.C.	Band 10
J. Mason	Band 10
T.A. Mason, N.E.B.S.M.	Band 10
A.D. Munro, H.N.D.	Band 10
J. Abernethy	Band 11 (P/T) (HELM)
J-M. Ford	Band 11 (P/T)
M. Torrie	Band 11 (P/T) (HELM)

Administrator
W.A. Patterson, H.N.D. Band 8

Biomathematics and Statistics Scotland (BioSS)

King's Buildings, University of Edinburgh

Director: R.A. Kempton, M.A., B.Phil., C.Stat, FRSE.[16]	Band 3
C.A. Glasbey, M.A., Dip. Math. Stats., Ph.D., D.Sc., M.I.S.I.[18,19]	Band 3 (IMP)
D. Husmeier, B.Sc., Ph.D.	Band 5 (SPD)
I.J. McKendrick, B.Sc., Ph.D.	Band 5 (SPD) (P/T)
G.R. Marion, B.Sc., M.Sc., Ph.D.	Band 5 (SPD)
J. Sales, B.Sc., M.Sc.	Band 5 (SPD)
J.M. Dickson, B.Sc.	Band 5 (P/T)
A.M.I. Roberts, B.Sc., M.Sc.	Band 5
D.J. Allcroft, B.Sc., M.Sc., Ph.D.	Band 6 (PD)
A.D. Mann, B.Sc.	Band 6
J.C. Wood, B.Sc.	Band 6
M.A.M. Kirkwood, D.A.	Band 7
Administration Officer: E.M. Heyburn, M.A.	Band 7
J. Clabby	Band 8 (P/T)
D. Glancy	Band 10 (P/T)

West of Scotland Unit, Hannah Research Institute

Head: S. Brocklehurst, B.Sc., Ph.D.	Band 5 (SPD)
I.M. Nevison, M.A.	Band 6 (PD)

Aberdeen Unit, Rowett Research Institute

Head: G.W. Horgan, B.A. M.Sc., Ph.D.	Band 4
C-D. Mayer, M.Sc., Ph.D.	Band 5 (SPD)
G. Zuur, M.Sc., Ph.D.	Band 6 (PD) (P/T)

Environmental Modelling Unit, The Macaulay Institute

Head: D.A. Elston, B.A., M.Sc., Ph.D.	Band 4
M.J. Brewer, B.Sc., Ph.D.	Band 5 (SPD)
D.M. Walker, B.Sc., M.Sc., Ph.D.	Band 5 (SPD)
J.M. Potts, B.Sc., M.Sc., Ph.D.	Band 6 (PD)
E.I. Duff, B.Sc.	Band 6

Dundee Unit, Scottish Crop Research Institute

Head: J.W. McNicol, B.Sc., M.Sc.[9]	Band 4
C.A. Hackett, B.A. Dip. Math. Stats., Ph.D.	Band 4 (Prom. Jul 01)
K.M. MacKenzie, B.Sc., M.Sc., Ph.D.	Band 6 (PD)
F.G. Wright, B.Sc., M.Sc., Ph.D.	Band 5 (SPD)
I. Milne, B.Sc., Ph.D.	Band 6

Mylnefield Research Services (MRS)

Managing Director: N.W. Kerby, B.Sc., Ph.D., C.Biol., F.I. Biol.
Commercial Director: J.B. Snape, M.A., M.Sc., Ph.D., C.Biol., M.I.Biol.
Administrative Executive Officer: A. Ross, H.N.C., C.P.P.
Commercialisation Officer: L. Beaton, H.N.C., D.M.S.
Personal Secretary/Administrative Assistant: H. Wilson.
Administrative Assistant: M. Beattie
Consultants:
W.C. Christie, M.B.E., B.Sc., Ph.D., D.Sc., C.Chem., F.R.S.E., F.R.S.C.
F. Gunstone, B.Sc., Ph.D., D.Sc., F.R.S.C., F.R.S.E., C.Chem.
G.R. Mackay, M.B.E., B.Sc., M.Sc., C.Biol., F.I.Biol.

D. Coyle
J.E. Fairlie, O.N.C., B.Sc.
K. Jackson, B.Sc.
S.N. Jennings, B.Sc.
J. Marshall, B.Sc.
R. Razzo,
C.M. Reid, B.Sc.
V-M. Rokka, Ph.D.
S. Rowbottom, O.N.C., H.N.C.
K. Wood

Honorary Research Professors

Professor P.M.A. Broda, M.A., M.Sc., Ph.D., D.Sc., Hon.D.Sc.
Professor M.C.R. Davies, BSc., Dip. Theol., M.Phil., Ph.D., C.Eng., M.I.C.E. F.T.G.
Professor G.M. Gadd, B.Sc., Ph.D., C.Biol., D.Sc., F.I. Biol.
Professor F. Gunstone, B.Sc., Ph.D., D.Sc., F.R.S.C., F.R.S.E., C.Chem.
Professor B.D. Harrison, C.B.E., B.Sc., Ph.D., D.Ag.For., F.R.S., F.R.S.E.
Professor N.L. Innes, O.B.E., B.Sc., Ph.D., D.Sc., C.Biol., F.I.Biol., F.R.S.E.
Professor H.G. Jones, M.A., Ph.D.
Professor J. Raven, Ph.D., F.R.S.E., F.R.S.
Professor J Sprent, O.B.E., B.Sc., D.Sc., Ph.D., A.R.C.S., F.R.S.E.

Honorary Research Fellows

A. Blackwell, B.Sc., Ph.D., M.R.C.V.S.
F. Bransby, B.A., M.A., Ph.D.
J. Bown, B.Sc., Ph.D.
W.C. Christie, M.B.E., B.Sc., Ph.D., D.Sc., C.Chem., F.R.S.E., F.R.S.C.
A.J. Flavell, B.Sc., Ph.D.
C. Halpin, B.Sc., M.Sc., H.Dip., Ph.D.
L.L. Handley, B.A., B.Ed., M.Sc., Ph.D.
W.H. Macfarlane Smith, B.Sc., Ph.D., C.Biol., M.I.Biol., F.I.Mgt.
G.R. Mackay, M.B.E., B.Sc., M.Sc., C.Biol., F.I.Biol.
D.K.L. MacKerron, B.Sc., Ph.D.
Dr M.A. Mayo, B.Sc., Ph.D.
I.M. Morrison, B.Sc., Ph.D.
T. Newson, B.Sc., Ph.D.
W. Robertson., H.N.C., F.L.S
D.L. Trudgill, B.Sc., Ph.D., C.Biol., F.I.Biol., F.S.O.N.
N. White, B.Sc., Ph.D., C.Biol., M.I.Biol.

Resignations

Name	Unit	Band	Month
P. Baumgartner	QHN	6 PD	May 02
J. Clabby	BioSS	8	March 03
P. Dibdin	QHN	8	May 02
I. Geoghegan	SLIS	6	August 02
C. Goldmann	GD	8	December 02
H. Grant	PPI	7	April 02
T. Heilbronn	SLIS	6	May 02
J. Hillier	EMB	6 PD	August 02
M. Kutuzov	QHN	6 PD	January 03
J.S. Miller	GE	6 PD	July 02
J. Moir	CCC	7	November 02
J. Sillanpaa	PSI	6 PD	February 03
P. Torr	EMB	8	September 02
K. Wu	PSI	6 PD	October 02
K. Zhang	PSI	6 PD	April 02
X. Zhang	PSI	6 PD	April 02

Staff Retirements

Name	Unit	Band	Month
G. Ellis	PPI	7	February 03
J.W.S. Forrest	GE	4	June 02
L.L. Handley	PSI	4	November 02
E.A. Hunter	BioSS	4	February 03
R Lowe	HPCE	6	August 02
W.H. Macfarlane Smith	SLIS	4	April 02
G.R. Mackay	GD	3	December 02
D.K.L. MacKerron	EMB	4	March 03
I.M. Roberts	CCC	4	October 02
A.G. Stewart	BioSS	10	November 02
H.E. Stewart	HPCE	6 PD	July 02
D.L. Trudgill	EMB	3	May 02
T Woodford	HPCE	4	June 02

Redundancies, Flexible & Compulsory Retirements

Name	Unit	Band	Month
D.J.F. Brown	HPCE	4	March 02
M.A.M. Mayo	GE	3	March 02
I. Paxton	FHR	6	March 02
C. Skelly	FHR	6	March 02

Postgraduate Students

Name	Unit	Subject
M.A.M. Adam	PPI	Identification and molecular characterisation of root knot nematodes.
H. Al-Meniae	GD	Matching soil, water and genotype for barley cultivation in Kuwait.
M.A.Y.Akhond	GE	Gene targeting in crop plants.
A.Blake	QHN	Metabolic profiling of bryophytes for bioactive products.
J. Bolandandam	GE	Study of resistance mechanisms in potato leafroll virus in diploid and tetraploid potato.
K. S. Caldwell	GD	Grain hardness: linkage disequilibrium in barley.
L.M. Castelli	PPI	Novel sources of resistance to potato cyst nematodes (*Globodera rostochiensis* & *G.pallida*) in wild potato species held in the Commonwealth Potato Collection.
L.J.M. Ducreux	QHN	Manipulation of carotenoid metabolism in tubers of *Solanum tuberosum* and *S. phureja* using an antisense approach.
S. Flynn	PPI	The identification of candidate effectors and elicitors in *Erwinia.*
C. Furlanetto	PPI	Genes encoding oesophageal gland secreted proteins involved in host-parasite and/or nematode-virus interactions of *Xiphinema* index.
E. Gilroy	PPI	The role of plant defence genes in the hypersensitive response.
C.M. Goncalves De Oliveira	HPC	Development of polymerase chain reaction diagnostics (PCRDs) for *Xiphinema* species (*Nematoda: Longidoridae*) occurring in Brazil.
J. Heilbronn	PPI	Characterisation of signalling genes induced by *erwinia* in potato.
M. Holeva	PPI	A study of the pathogenicity and molecular biolgy of *Erwinia carotovora* subsp. *Atroseptica.*
R. Holeva	HPC	Molecular diagnostics of trichodorid nematodes and tobacco rattle virus.
H. L Kuan	PSI	What is the link between microbial diversity and soil resilience?
H.Liu	GD	Molecular analysis of grain development in barley.
L. Mazzitelli	QHN	Physiological, biochemical and molecular characterisation of bud dormancy in woody perennial species.
C. Mitchell	HPC	Cane fruit: Novel approaches for ICM in fresh and processed crops.
W Morris	QHN	Characterisation and manipulation of gene expression during carotenogenesis in potato tubers.
S. Sharma	GE	Development of an efficient somatic embryogenesis in potato tubers.
K. Stamati	GD	Biodiversity of sub-artic willow.
N. Taleb	HPC	Determination of the molecular basis of genetic resistance to *Phytophthora infestans* in potato.

Short-Term Workers and Visitors

Name	Country of origin	Programme	Month/yr of arrival	Length of stay
M. Andrews	UK	HPCE	May 03	2 months
R. T. Arnau	Spain	EMB	Sep 02	3 months
G. D. Arteaga	UK	QHN	Jun 02	3 months
G. Briggs	UK	QHN	Jun 02	3 months
K. Brown	UK	PPI	Jun 02	3 months
T. Dimakopoulou	Greece	GE	Mar 03	3 months
L. Duarte	Portugal	HPCE	Sep 02	6 weeks
E. Fanelli	Italy	PPI	Jul 03	9 months
T. Frenzel	Germany	QHN	Apr 02	6 weeks
S. Fyffe	UK	QHN	Aug 02	6 months
L. R. Garcia	Spain	EMB	Sep 02	3 months
G. van der Heijden	Netherlands	BioSS	Apr 02	3 months
G. Huang Huang	Malaysia	BioSS	Aug 02	2 months
J. Hübschen	Germany	HPCE	Feb 03	2 months
O. Kiselyova	Russia	GE	Feb 03	2 weeks
M. Koprivica	Yugoslavia	HPCE	Sep 02	1 month
O. Lavrova	Russia	PPI	May 03	6 weeks
S. Lazarova	Bulgaria	HPCE	Jun 02	12 months
C. R. Lopez	Canary Islands	GD	Aug 02	5 months
F. Nabugoomu	Uganda	BioSS	Sep 02	4 months
T. Pettitt	Australia	BioSS	Dec 02	5 weeks
M.D. Rizza	Uruguay	HPCE/GD	Jul 02	6 weeks
R. Sharma	UK	PPI	Oct 02	6 months
C. Silvar	Spain	HPCE	Sep 02	3 months
A. Smith	UK	HPCE	Jul 02	4 weeks
T. Stroganova	Russia	GE	Feb 02	12 months
J. Sutton	UK	EMB	Mar 02	5 months
L. Tedone	Italy	QHN	Jun 02	10 months
N. Toplak	Slovenia	GE	Mar 03	2 weeks
T. Uehara	Japan	HPCE	Nov 02	9 months
J. Uhrig	Germany	GE	May 02	3 weeks
K. Wypijewski	Poland	CCC	Sep 02	3 months
L. Yates	UK	QHN	Jun 02	6 weeks
B. Zhang	China	PSI	Jan 03	2 months

Longer-Term Workers and Visitors

Name	Country of origin	Programme	Month/yr of arrival	Length of stay
C. Johnstone	UK	EMB	Aug 02	3 years
G. Muehlbauer	USA	GD	Jun 02	1 year

Editorial Duties

Name	Position	Journal Title
H. Barker	Editor	Annals of Applied Biology
A.G. Bengough	Editor	Annals of Botany
A.N.E. Birch	Editor	IOBC Bulletins for Working Groups (WPRS Section)
	Editor	IOBC GMO Guidelines Publications (Global Section)
R.M. Brennan	Associate Editor	Journal of Horticultural Science and Biotechnology
M.J. Brewer	Associate Editor	Journal of Statistical Computation and Simulation
M.F.B. Dale	Editor	Annals of Applied Biology
D.A. Elston	Associate Editor	Applied Statistics
	Associate Editor	Journal of Agricultural, Biological and Environmental Statistics
J.M. Duncan	Associate Editor	Journal of Horticultural Science and Biotechnology
S.C. Gordon	Joint Editor	IOBC/wrps Bulletin
C.A. Glasbey	Associate Editor	Journal of Royal Statistical Society, Series B
	Editor	Applied Statistics
J. Graham	Associate Editor	Journal of Horticultural Science and Biotechnology
	Reviewer	USDA Small Business Innovative Research
B.S. Griffiths	Editorial Board	Pedobiologia
J.R. Hillman	Publication Committee	Journal of Horticultural Science
	Editorial Board	Agricultural Systems
	Editorial Board	Journal of Agricultural Science
G.W. Horgan	Editorial Board Member	British Journal of Nutrition
A.T. Jones	Editor	Annals of Applied Biology – Description of Plant Viruses
J.T. Jones	Editorial Board	Journal of Helminthology
R. Neilson	Deputy Chief Editor	Russian Journal of Nematology
	Associate Editor	ZooTaxa
A.C. Newton	Editor	Plant Pathology
	Editor and Publisher	Cereal Rusts and Powdery Mildews
P.F. Palukaitis	Editor	Journal of General Virology
	Editorial Advisory Board	Plant Pathology Journal
	Member of Editorial Board	Molecular Plant-Microbe Interactions
W. Powell	Associate Editor	Molecular Ecology
D.J. Robinson	Editor	Descriptions of Plant Viruses
	Editorial Board	Journal of Virological Methods
M. Taliansky	Editorial Board	Journal of General Virology
I. Toth	Assistant Editor	Molecular Plant Microbe Interactions
R. Waugh	Editorial Advisory Board	Plant Biotechnology Journal
B. Williamson	Deputy Chairman	Annals of Applied Biology

Service on External Committees or Organisations

Name	Position	Committee or Organisation
D.J. Allcroft	Member	RSS Edinburgh Local group committee
T.J.W. Alphey	Secretary	Committee of Heads of Agricultural and Biological Organisations in Scotland
	Secretary	Scottish Management Advisory Committee
A.G. Bengough	Co-Chair	EU Working Group on Modelling Rhizosphere
A.N.E. Birch	Member	Steering Group, IOBC GMO Guidelines project Convenor IOBC Working Group on Breeding for Resistance to Insects and Mites
	Fellow	Royal Society of Entomologists, London
V.C. Blok	Executive Board Member	Society of Nematology
	Committee Member	Association of Applied Biologists, Nematology Group
J.E. Bradshaw	Chairman	Potato Section, EUCARPIA
	Committee Member	BBSRC Brassica IGF Steering Committee
R.M. Brennan	Adviser	GSK Blackcurrant Research Committee
	Member	Advisory Group to Scottish Berry Programme
S. Brocklehurst	Member	HRI Ethical Review Committee
J.W.S. Brown	SCRI Representative	European Plant Sciences Organisation
G.J. Bryan	Member	Advisory Committee NSF Potato Genome Project (USA)
M.J. De,Maine	Member	BBSRC Joint Committee on Health & Safety
	Member	SABRI Safety Officers' Group
J.M. Duncan	Member of Steering Committee	GILB (Global Initiative on Late Blight)
D.A. Elston	Member	Scientific and Technical Advisory Group, UK Environmental Change Network
	Chair	Royal Statistical Society Highland Local Group
B.P. Forster	Chairman	COST Action 851, Gametic cells
	Co-ordinator	Barley chromosome organisation
	Assistant Co-ordinator	International Triticeae Mapping Initiative
C.A. Glasbey	Member	EPSRC Peer Review College
	Chairman	RSS Statistical Image Analysis and Processing study group
	Member	RSS Editorial Policy Board
	Member	RSS Programme Committee
	Member	Conference Advisory Committee of International Biometric Society
P.A. Gill	Treasurer	UK Controlled Environment Users Group
	Member	Institute of Horticulture: Horticultural Affairs Standing Committee
P.D. Hallett	Meetings Secretary	Scottish Soils Discussion Group, British Society of Soil Science
J.R. Hillman	Chairman	SCRI/SASA/SAC Liaison Group
	Chairman	Tayside Biocentre Group
	Deputy Chairman	Board of Directors, Mylnefield Research Services Ltd
	Member	Board of the Mylnefield Trust
	Member	Board of Mylnefield Holdings Ltd
	Chairman	Committee of Heads of Agricultural and Biological Organisation in Scotland
	President	Agriculture and Food Section, the British Association for the Advancement of Science
	Member	ECRR Board of Management
	Member	SNSA Adviser to Committee
	Member	Court of University of Abertay Dundee and its Audit Committee
	Member	Senate, University of Dundee
	Member	University of Strathclyde Sub-Board for the Degree of B.Sc. in Horticulture
	Member	Tayside Economic Forum
	Member	Perth & Kinross Agricultural Forum
	Member	Board of Directors, BioIndustry Association
	Adviser	International Foundation for Science, Stockholm
	Member	House of Lords Rural Economy Group
	Member	Forum for Representation of Industrial and Environmental Biotechnology Suppliers (Department of Trade and Industry)
D.L. Hood	Secretary & Treasurer	Scottish Society for Crop Research
G. W. Horgan	Member	RSS Highland Local Group
E.A. Hunter	Member	Editorial Board of Food Quality & Preference
	Member	SAC – Edinburgh, Animal Experiments Committee
	Member	Scientific Committee of the ASU conference, Rennes, France.
	Member	Inter-departmental Statisticians Group (IDSG)
	Member	Herbage VCU group
	Member	Scientific Committee, Sensometrics Conference, Davis, California, USA
J.T. Jones	Honorary Treasurer	British Society for Parasitology
I.Kelly	Director	Dundee Science Centre
	Member	Council of the Royal Scottish Geographical Society
	Member	Research Committee of the Royal Scottish Geographical Society

Name	Position	Committee or Organisation
R.A. Kempton	Member	International Statistical Institute Risk Analysis Committee
	Member	Fisher Memorial Committee
	Member	Edinburgh Centre for Rural Research
	Member	Advisory Committee on Forest Research
	Member	Advisory Committee, Mres Mathematics in the Living Environment, University of York
	Member	Executive Committee, International Centre for Mathematical Sciences
	External Reviewer	FSA Food Safety Programme
A.K. Lees	Elected Board Member	British Society for Plant Pathology
	Member	Crop Protection in Northern Britain
J. Liu	Member	EPSRC Peer Review College
S.A. MacFarlane	Committee Member	Virus Group, Association of Applied Biology
	Committee Member	Virus Group, Society for General Microbiology
D.K.L. MacKerron	Secretary	SSCR Potato Crop Sub-committee
	Chairman	Section Physiology, EAPR
U.M. McKean	Joint Chair	Scottish Agricultural Librarians' Group
I.J. McKendrick	Member	MRI Ethical Review Committee
R. Neilson	Governing Board Member	European Society of Nematologists
I.M. Nevison	Member	SAC Auchincruive Ethical Review Committee
A.C. Newton	Member	Conference Organising Committee and Cereals Session Organising Committee, Crop Protection in Northern Britain
	Member	Standing Committee, Association for Crop Protection in Northern Britain
	Board Member	European and Mediterranean Cereal Rusts Foundation
	Committee Member	United Kingdom Cereal Pathogen Virulence Survey
	External Assessor	DEFRA Arable Crop Genetic Improvement and Breeding Research Programme
P.F. Palukaitis	Member	ICTV Satellites Study Group
	Member	ATCC Tobamovirus Advisory Group
W. Powell	Managing Director	International Triticeae Mapping Initiative Management Office (SCRI)
	Member	BBSRC Initiative on Gene Function (IGF)
	Member	Genetical Society Committee (Quantitative Genetics), British Society of Plant Breeders, Working Party on Biotechnology
	Member	Advisory Board for Scottish Informatics Mathematics Biology & Statistics (SIMBIOS) Centre (2001)
	Member	External Review Team for ICARDIA (Syria), IITA (Nigeria), VIB (Belgium) and CIP (Peru)
	External examiner	Genetics (B.Sc.) and M.Sc. at UCW Aberystwyth
	External examiner	Genetics (M.Sc.) at the University of Birmingham
	Committee Member	DEFRA Sustainable Arable Link Programme
G. Ramsay	Committee Member	UK Potato Quarantine Unit review committee
A.G. Roberts	Committee Member	Royal Microscopical Society, Cell Biology Section
A.M.I. Roberts	Secretary	Inter-departmental Statisticians' Group for National List and Seeds Committee
	Member	UPOV Technical Working Party on Automation and Computer Programs
	Statistician	Potato VCU group
	Statistician	Vegetable DUS
	Statistician	SASA Ethical Review Committee
D.J. Robinson	Member	ICTV Tobamovirus & Tobravirus Study Group
	Member	ICTV Umbravirus Study Group
S.E. Stephens	Joint Chair	Scottish Agricultural Librarians' Group
	Member	Information Services Group – Scottish Library Association Committee
	Member	Tayside and Fife Library and Information Network
	Working Group Chair	British Research Institutes Serials Consortium (BRISC)
	Secretary	Research Councils Library and Information Consortium (RESCOLINC)
	Chair	BBSRC Research Institutes Librarians Committee (BRILCOM)
J.S. Swanston	Secretary	SSCR Cereal Crops Sub-Committee
M. Taliansky	Chairman	Umbravirus Study Group of International Committee on Taxonomy of Viruses
	Member	Plant Virus Subcommittee of International Committee on Taxonomy of Viruses
	External Examiner	Stellenbosch University, South Africa
I. Toth	Director	British Society for Plant Pathology
	Committee Member	Crop Protection in Northern Britain
	Committee Member	BSPP President's Meeting
R. Viola	Chairman	European Association for Potato Research (Physiology Section)
J.D. Watt	Member	Scottish Management Advisory Committee
	Company Secretary	Mylnefield Research Services (MRS) Ltd.
	Secretary	Mylnefield Trust
	SABRI Representative	BBSRC Joint Negotiating and Consultative Committee
B. Williamson	Treasurer	Association for Crop Protection in Northern Britain

Awards and Distinctions

Name	Programme	Degree/Award/Distinction/Appointment
Konstantina Boutsika	HPC	Ph.D., University of Dundee, Molecular identification and phylogenies of virus and non-virus vector trichodorid nematodes
Dr Rex Brennan	GD	Royal Horticultural Society, Jones-Bateman Cup for fruit breeding
Katie Caldwell	GD	SABRI Postgraduate Prize
Qing Chen	HPC	Ph.D., University of Dundee, Protein based approaches to the study of Xiphinema nematodes
Jim Godfrey, Chair Governing Body		OBE
Kirsty Harris	PSI	M.Phil., University of Abertay, Visualisation of interactions between soil physical conditions and fungi
Ingo Hein	PPI	Ph.D., University of Dundee, Discovering resistance pathways in response to elicitors and powdery mildew attack in barley
Professor John Hillman	Director	Royal Caledonian Horticultural Society, Scottish Horticultural Medal
Shaukat Hussain	HPC	Ph.D., University of Abertay, Diagnostics and epidemiology of Phytophthora infestans, the cause of potato blight
Lucy MacKinnon	GE	Ph.D., University of Dundee, Genetic Transformation of *Cannabis sativa* Linn: A Multi Purpose Fibre Crop
Iain R. Milne	BIOSS	Ph.D., University of Dundee, OGRE: a software visualization system for novice programmers learning C++
Barnaly Pande	GD	Ph.D., University of Dundee, The genetic analysis of traits of economic importance in the principal cultivated potato Solanum tuberosum spp tuberosum
Alison Prior	PPI	Ph.D., University of Glasgow, Analysis of the expression, structure and function of nematode lipid-binding proteins
Dr Alison Roberts	CCC	Irene Manton Award for best UK Botanical Ph.D. Thesis of 1999
Keith Stewart	HPC	Ph.D., University of Oxford, Abiotic stress and mlo resistance to barley powdery mildew
Mark Wood	BIOSS	Ph.D., University of Aberdeen, Object shape and brightness comparison using wavelets

Rex Brennan

Katie Caldwell

SCRI Research Programme
2002-2003

SEERAD funded research programme showing: SEERAD project number; Title (prefixed ROA for ROAMEd core-funded projects; FF for Flexible Fund projects); Scientific Project Leader. In addition to this list, there are research projects undertaken on behalf of various bodies, including other governmental bodies, commerce and levy boards.

SCR/525/99	ROA Interactions between the structure of soil habitats and biological processes	Bengough G
SCR/526/99	ROA Integrative mapping of the long arm of barley chromosome 5H	Thomas W T B
SCR/527/99	ROA Development of a graphical database for the visualisation of genotypic and phenotypic data in barley	Marshall D F
SCR/528/99	ROA Use of an accelerated marker assisted selection scheme to introgress novel variation for economically important traits into cultivated barley	Thomas W T B
SCR/536/00	ROA Development and application of chemical strategies to facilitate genetic and molecular marker studies of factors affecting quality traits in potatoes	Davies H V
SCR/537/00	ROA Biochemical approaches to define novel targets for the genetic improvement of malting barley	McDougall G J
SCR/538/00	ROA Optimising production and biodiversity of arable plants and invertebrates at patch and landscape scales. I. Arable plants	Squire G
SCR/539/00	ROA Self organisation of plant and canopy architecture in barley and feral brassicas: trade offs between production and defense	Squire G
SCR/540/00	ROA Genetics of cultivated potatoes	Bradshaw J E
SCR/541/00	ROA Genetic approaches to evaluation and utilisation of soft fruit germplasm	Brennan R
SCR/542/00	ROA Consequences of soil biodiversity for the functioning and health of agricultural soils in relation to C cycling dynamics and resilience	Griffiths B S
SCR/544/00	ROA Consequences of soil biological diversity for the functioning and health of agricultural soils in relation to N cycling processes. I. Soil microbial diversity and nitrification/denitrification processes	Wheatley R
SCR/545/00	ROA Detection, diversity and epidemiology of important viruses and their vectors in berryfruit crops and strategies for their effective control	Jones A T
SCR/546/00	ROA Development and use of molecular markers to study the epidemiology of late blight (*Phytophthora infestans*) of potato in Scotland	Cooke D
SCR/547/00	ROA Biodiversity in the antioxidant status and composition of Rubus and other soft fruit germplasm	Stewart D
SCR/549/00	ROA Characterisation of molecular interactions between soft rot erwinias and potato	Lyon G D
SCR/551/00	ROA Post-transcriptional control of gene function	Brown J W S
SCR/552/00	ROA Barley 'deletion' mutation grid	Waugh R
SCR/554/00	ROA Protein-protein interactions and the role of virus proteins in disease processes	Torrance L

SCR/557/01	ROA Targeted long-distance transport of macromolecules in plants	Oparka K
SCR/558/01	ROA Resistance to potato viruses: exploitation of host gene resistance and transgenic resistance to study resistance mechanisms and to develop resistant germplasm	Barker H
SCR/559/01	ROA Molecular biology of potato leafroll virus: aphid transmission and the establishment of infection in host plants	Barker H
SCR/560/01	ROA Molecular bases of resistance and susceptibility in potato and barley	Birch P R J
SCR/561/01	ROA Molecular bases of pathogenicity in potato cyst nematodes, *Xiphinema index* and *Phytophthora infestans*	Jones J
SCR/562/01	ROA Genetics of seedling root traits in barley	Forster B
SCR/563/01	ROA Conservation and utilisation of the Commonwealth Potato Collection	Mackay G R
SCR/564/01	ROA A gene map of the interval between GP21 and GP179 on potato linkage group V	Bryan G
SCR/565/01	ROA Identification and characterisation of bacterial artificial chromosome (BAC) clones from gene rich regions of the barley genome	Waugh R
SCR/566/01	ROA Produce and maintain pathogen-tested stocks of Rubus, Ribes and Fragaria germplasm and index for infection material imported into SCRI	Jones A T
SCR/571/01	ROA Ecological management and biotechnology	Squire G
SCR/572/01	ROA Computational biology	Marshall D F
SCR/573/01	ROA Functional analysis of novel genes from potato and barley	Lacomme C
SCR/574/01	ROA Development and application of metabolic profiling technologies to enhance the understanding of metabolic and developmental processess in plants	Deighton N
SCR/575/01	ROA Enhancing food quality and nutritional value through multidisciplinary approaches which exploit genetic and molecular diversity	Taylor M
SCR/576/01	ROA Sequence diversity and horizontal genomics (targeted gene discovery)	Waugh R
SCR/577/01	ROA Molecular plant diversity and germplasm resources	Waugh R
SCR/578/01	ROA Parallel gene expression technologies supporting the discovery of plant and pathogen genes important to agriculture and biotechnology	Machray G C
SCR/580/02	ROA Suppression of gene silencing by virus proteins	MacFarlane S
SCR/581/02	ROA Cell and tissue engineering in barley and potato	Machray G C
SCR/583/02	ROA Variation in pathogenicity in *Globodera* spp. in relation to host resistance	Phillips M S
SCR/584/02	ROA Approaches to regulate the L-ascorbic acid content of commercially important plants	Viola R
SCR/585/02	ROA Genetics of cultivated diploid potatoes	Bradshaw J E
SCR/586/02	ROA Cell-to-cell trafficking of macromolecules in plants	Oparka K J

SCR/587/02	ROA Optimising production and biodiversity of arable plants and invertebrates at patch and landscape scales. II. Invertebrates	Fenton B
SCR/588/02	ROA Consequences of soil biological diversity for the functioning and health of agricultural soils in relation to N cycling processes. II. Carbon and nitrogen fluxes among major plant and soil pools, using natural abundance stable isotopes	Scrimgeour C

SCR/516/97	FF Genetic mapping and molecular cloning of novel sources of resistance to Globodera pallida	Waugh R
SCR/522/98	FF Development of Rubus genotypes with transgenic resistance to raspberry bushy dwarf virus	Jones A T
SCR/555/00	FF Cereal transcriptome resources	Waugh R
SCR/556/00	FF Comparison of the molecular bases of pathogenicity in the model oomycetes Peronospora parasitica and Phytophthora infestans through a genomics approach	Birch P R J
SCR/568/00	FF Significance and mechanisms of landscape-scale gene flow	Ramsay G
SCR/569/00	FF Phytophthora diseases of soft fruit: determining their prevalence and the source of new outbreaks in Scotland	Duncan J M
SCR/570/00	FF Mechanical properties of primary cell walls by micro-stretching in vivo	Bengough A G
SCR/579/01	FF Development of robust, broad basedQTL maps to improve barley breeding	Thomas W T B
SCR/582/01	FF Cloning of avirulence genes from the oomycete plant pathogens Peronospora parasitica and Phytophthora infestans	Birch P R J
SCR/589/02	FF Novel methodologies and tools for the analysis of germplasm collections	Marshall D
SCR/808/94	FF Development of molecular biological and physiological techniques in studies of the interaction between microbes, nutrient cycling and vegetation among a range of agriculturally important pastures, to enable scaling from microcosm to field. + Phase 2.	Ritz K
SCR/818/95	FF Genetic engineering of crop plants for resistance to insect and nematode pests: effects of transgene expression on animal nutrition and the environment	Jones A T
SCR/823/97	FF Significance of physical heterogeneity for scaling of solute chemistry in soils from fine scale to subcatchment	Bengough G
SCR/824/97	FF Efficacy studies on a plant virus-based expression system and on alternative delivery routes for peptides and proteins with pharmaceutical, therapeutic and related uses for improving animal health, nutrition and welfare	Brown J W S
SCR/832/99	FF Identification and assessment of nutritional relevance of antioxidant compounds from soft fruit species	Davies H V
SCR/833/00	FF Microsatellites as population genetic markers	Powell W
SCR/834/01	FF Assessment of plant germplasm for bioactive molecules	Ramsay G

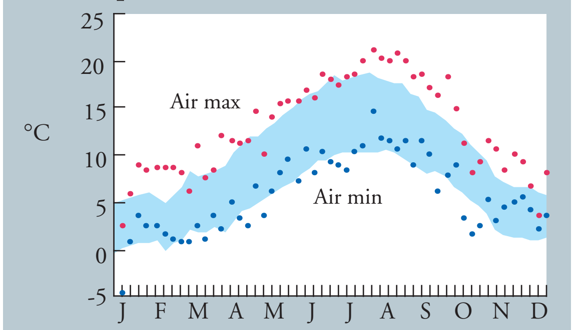
SCR/835/01	FF Genomic sequencing and proteomic analyses of the potato pathogenErwinia carotovora subsp. Atroseptica (Eca) and the animal pathogen Chlamydophila abortus (Ca)	Toth I
SCR/837/01	FF Biodiversity: taxonomy, genetics and ecology of Sub-arctic willow Scrub	Russell J
SCR/901/02	FF Soil stability and resilience: the interplay between biological and physical recovery from stress	Griffiths B S
SCR/902/02	FF Functional characterisation of appressorial infection stage-specific proteins from Phytophthora infestans	Birch P R J

Meteorological Records

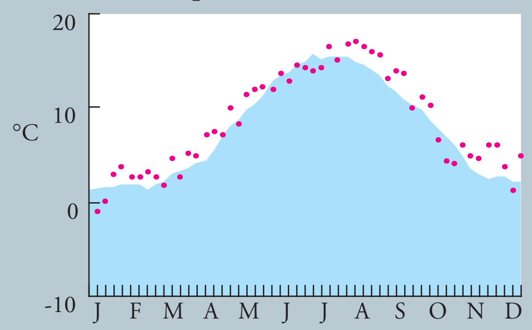
D. Petrie & M. Grassie

Detailed meteorological records are kept regularly at SCRI. The graphs shown are for weekly values for 2002 and the long term average for 1961-1990( ).

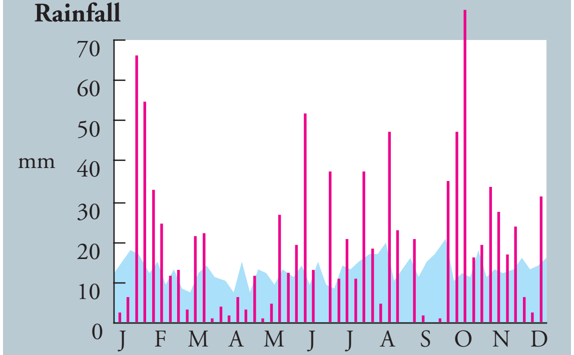
Air temperature



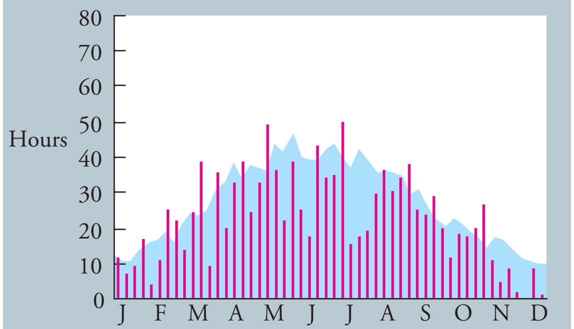
10cm soil temperature



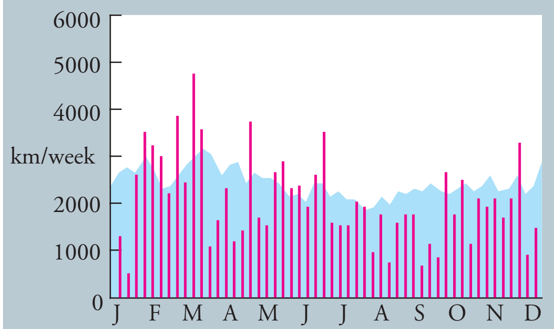
Rainfall



Sunshine



Run of wind



Institutes supported by the Biotechnology and Biological Sciences Research Council

BBSRC Office	Polaris House, North Star Avenue, Swindon, Wilts SN2 1UH	01793-413200
BBSRC Bioscience IT Services	West Common, Harpenden, Herts AL5 2JE	01582-714900
Babraham Institute	Babraham Hall, Babraham, Cambridge CB2 4AT	01223-496000
Laboratory of Molecular Signalling	Babraham Institute, P.O. Box 158, Cambridge CB2 3ES	01223-496406
Institute for Animal Health		
Compton Laboratory	Compton, Near Newbury, Berkshire RG20 7NN	01635-578411
Pirbright Laboratory	Ash Road, Pirbright, Woking, Surrey GU24 0NF	01483-232441
BBSRC & MRC Neuropathogenesis Unit	Ogston Building, West Mains Road, Edinburgh EH9 3JF	0131-667-5204
Institute of Arable Crops Research		
Rothamsted	Harpenden, Herts AL5 2JQ	01582-763133
Broom's Barn	Highham, Bury St. Edmunds, Suffolk IP28 6NP	01284-812200
Institute of Food Research	Norwich Research Park, Colney, Norwich NR4 7UA	01603-255000
Institute of Grassland and Environmental Research		
Aberystwyth Research Centre	Plas Gogerddan, Aberystwyth, Dyfed SY23 3EB	01970-823000
North Wyke Research Station	Okehampton, Devon EX20 2SB	01837-883500
Bronydd Mawr Research Station	Trecastle, Brecon, Powys LD3 8RD	01874-636480
Trawsgoed Research Farm	Trawsgoed, Aberystwyth, Dyfed SY23 4LL	01974-261615
John Innes Centre	Norwich Research Park, Colney, Norwich NR4 7UH	01603-450000
Roslin Institute	Roslin, Midlothian EH25 9PS	0131-527-4200
Silsoe Research Institute	Wrest Park, Silsoe, Bedford MK45 4HS	01525-860000
Horticultural Research International		
HRI, East Malling	West Malling, Maidstone, Kent ME19 6BJ	01732-843833
HRI, Wellesbourne	Wellesbourne, Warwick CV35 9EF	01789-470382

Scottish Agricultural and Biological Research Institutes

Hannah Research Institute	Ayr, Scotland KA6 5HL	01292-674000
The Macaulay Institute	Craigiebuckler, Aberdeen AB9 2QJ	01224-318611
Moredun Research Institute	Pentlands Science Park, Bush Loan, Penicuik, Midlothian EH26 0PZ	0131-445-5111
Rowett Research Institute	Greenburn Road, Bucksburn, Aberdeen AB21 9SB	01224-712751
Scottish Crop Research Institute	Invergowrie, Dundee DD2 5DA	01382-562731
Biomathematics and Statistics Scotland (Administered by SCRI)	University of Edinburgh, James Clerk Maxwell Building, King's Buildings, Mayfield Road, Edinburgh EH9 3JZ	0131-650-4900

List of Abbreviations

AAB	Association of Applied Biologists
ACRE	Advisory Committee on Releases to the Environment
ADAS	Agricultural Development and Advisory Service
BBSRC	Biotechnology & Biological Sciences Research Council
BCPC	British Crop Protection Council
BioSS	Biomathematics and Statistics Scotland
BPC	British Potato Council
BSPB	British Society of Plant Breeders
BTG	British Technology Group
CAPS	Cleaved Amplified Polymorphic Sequence
CEC	Commission of the European Communities
CHABOS	Committee of Heads of Agricultural and Biological Organisations in Scotland
CIP	International Potato Centre - Peru
COST	European Co-operation in the field of Scientific and Technical Research
DEFRA	Department for Environment, Food and Rural Affairs
DfID	Department for International Development
EAPR	European Association for Potato Research
ECRR	Edinburgh Centre for Rural Research
ECSA	European Chips and Snacks Association
EHF	Experimental Husbandry Farm
ELISA	Enzyme linked immunosorbent assay
EPPO	European Plant Protection Organisation
ESTs	Expressed Sequence Tagged Sites
FF	Flexible Funding (SEERAD)
FLAIR	Food-Linked Agro-Industrial Research
FSE	Farm Scale Evaluation
GILB	Global Initiative on Late Blight
GIUS	Glasshouse Investigational Unit for Scotland
GMHT	Genetically Modified Herbicide Tolerant
H-GCA	Home-Grown Cereals Authority
HDC	Horticultural Development Council
HPLC	High Performance Liquid Chromatography
HRI	Hannah Research Institute
IACR	Institute of Arable Crops Research
ICTV	International Committee for the Taxonomy of Viruses
IOBC	International Organisation for Biological Control
IMP	Individual Merit Promotion
ISHS	International Society for Horticultural Science
ISPP	International Society for Plant Pathology
IVEM	Institute of Virology and Environmental Microbiology
MAFF	Ministry of Agriculture Fisheries and Food
MLURI	Macaulay Land Use Research Institute (now the Macaulay Institute)
MRI	Moredun Research Institute
NERC	National Environmental Research Council
NFT	National Fruit Trials
NFU	National Farmers Union
NIR	Near Infra-Red
NMR	Nuclear Magnetic Resonance
NPTC	National Proficiency Test Council
ORSTOM	Organisation for research in science and technology overseas
PCR	Polymerase Chain Reaction
PD	Post-doctorate
PIC	Product Innovation Centre
PVRO	Plant Variety Rights Office
RAPD	Randomly Amplified Polymorphic DNA
RFLP	Restriction Fragment Length Polymorphism
RNAi	RNA interference
RRI	Rowett Research Institute
SABRI	Scottish Agricultural and Biological Research Institutes
SAC	Scottish Agricultural College
SASA	Scottish Agricultural Science Agency
SCRI	Scottish Crop Research Institute
SEB	Society for Experimental Biology
SEERAD	Scottish Executive Environment and Rural Affairs Department
SET	Scottish Enterprise Tayside
SNSA	Scottish Nuclear Stocks Association
SPD	Senior Post-doctorate
SSCR	Scottish Society for Crop Research
STS	Sequence Tagged Sites
UNDP	United Nations Development Programme
WHO	World Health Organisation